,165

NHB 7150.1

[redacted]

13047

REFERENCE EARTH ORBITAL RESEARCH AND APPLICATIONS INVESTIGATIONS

(BLUE BOOK)

VOLUME V • COMMUNICATIONS/NAVIGATION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

JANUARY 15, 1971

[redacted]

REFERENCE EARTH ORBITAL RESEARCH AND APPLICATIONS INVESTIGATIONS

(Blue Book)

VOLUME V
COMMUNICATIONS/NAVIGATION

15 January 1971

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PREFACE

The purpose of the preliminary edition of the "Reference Earth Orbital Research and Applications Investigations" set forth in this document is to:

a. Provide criteria, guidelines, and an organized approach for use in the Space Station and Space Shuttle Program Definition Phase and ancillary studies in designing a flexible, multidisciplinary orbiting space facility and logistics system.

b. Define a manned space flight research capability to be conducted in earth orbital Space Stations and Shuttles.

c. Provide a basis for potential follow-on programs.

The term "Functional Program Element" (FPE) used in this document describes a gross grouping of experiments characterized by the following two dominant features:

a. Individual experiments that are mutually supportive of a particular area of research or investigation, and

b. Experiments that impose similar and related demands on the Space Station Support Systems.

The research and applications investigations as set forth herein depart from a heterogeneous collection of individual experiments and are designed toward a "research facility" and "module" approach. The term FPE and "module" are used somewhat interchangeably in this publication although this relationship is unintentional. Thus, a particular FPE may be described which does not fully utilize the capability of a complementary module but would, however, permit flexibility in experiment planning.

Functional Program Elements and experiments covered in this document are envisioned for flight with the initial Space Station and the Space Shuttle. Only those FPE's and experiments which can reasonably be expected to be accomplished during the first few years of the Space Station and Space Shuttle have been described in detail in this document. However, for the most part, these FPE's are considered to be open-ended so that their utility could be extended.

This publication is applicable to all NASA program elements and field installations involved in the Space Station and Space Shuttle program.

The supply of this document is limited. Therefore, for those procurement actions involving only a certain portion (or portions) of this handbook, the cognizant NASA installations shall abstract from this handbook only such portions as apply to a given RFP or contract action.

This publication was prepared in conjunction with NASA Headquarters Program Offices and field installations involved in payload planning and with industry participation. It is an updated and revised version of the Candidate Experiment Program for Manned Space Stations, NHB-7150.xx, dated September 15, 1969 and the changes thereto dated June, 1970. These earlier versions are hereby cancelled.

The material contained in each volume has been produced under the guidance of Review Groups composed of scientific personnel at NASA Headquarters, MSFC, LaRC, MSC, LeRC, GSFC and ARC. The purpose of this effort was not only to revise and update the experiment programs but also to establish the Space Shuttle as well as the Space Station requirements.

Volume I, Summary, presents the background information and evolution of this document; the definition of terms used; the concepts of Space Shuttle, Space Station, Experiment Modules, Shuttle-sortie Operations, and Modular Space Station; and in Section IV, a summary of the Functional Program Element (FPE) requirements is presented.

Volumes II thru VIII contain detailed discussions of the experiment programs and requirements for each discipline. The eight volumes are:

Volume I	Summary
Volume II	Astronomy
Volume III	Physics
Volume IV	Earth Observations
Volume V	Communications/Navigation
Volume VI	Materials Sciences & Manufacturing
Volume VII	Technology
Volume VIII	Life Sciences

TABLE OF CONTENTS

TABLE OF CONTENTS (Contd)

TABLE OF CONTENTS (Contd)

LIST OF ILLUSTRATIONS

LIST OF TABLES

INTRODUCTION

Communications/Navigation is a new discipline incorporated within the Blue Book update task. A typical set of experiments has been selected from the broad field of communications and navigation to fully exercise this discipline within those areas wherein man is important in carrying out the experiments.

The basis for the selected experiments has been the "Earth Orbital Experiment Program and Requirements Study" (Contract NAS1-9464) performed for the Langley Research Center (LaRC) by McDonnell-Douglas Corporation and TRW Systems (subcontractor).

A review and examination of this selection of experiments has defined laboratory functions and equipment that specify a research facility operating within certain defined constraints and manned by research scientists skilled as electronic engineers, electromechanical technicians, optical technicians and microwave specialists.

At the present time the Communications/Navigation discipline contains only the one Functional Program Element: the Communications/Navigation Research Facility described in Section 1 of this volume.

SECTION 1

1. COMMUNICATIONS/NAVIGATION RESEARCH FACILITY

1.1 GOALS AND OBJECTIVES

1.1.1 GOALS. The goals of this functional program element (FPE) are to facilitate continued and expanded application of space technology and satellite systems. Man's unique capabilities as a research scientist in space may be used to provide for increased national and international needs for communications with and between earthbound airborne and spaceborne terminals, and to improve continually the capabilities for terrestrial, air, and space vehicle navigation and traffic control.

1.1.2 OBJECTIVES. Several continuing broad objectives guide the description of the Communications/Navigation Research Facility to serve its intended goals. These are:

a. Develop and demonstrate satellite systems and spacecraft technology applicable to space communications, navigation, and traffic control needs.

b. Optimize the use of the electromagnetic spectrum for communications and navigation satellite systems.

c. Provide fundamental understanding of the space communications and navigation sciences to permit NASA to fulfill its role as space communications and navigation consultant to government and industry.

To fulfill the goals and objectives of the Communications/Navigation Research Facility, this FPE describes a space laboratory in which man may effectively increase experiment efficiency by certain setup, calibration, and limited maintenance steps. In addition, man may monitor experiment progress and perform preliminary data evaluation to verify proper equipment functioning and may terminate or redirect experiments to obtain the most desirable end result.

1.2 PHYSICAL DESCRIPTION

A typical set of candidate experiments selected by the Com/Nav Review Group is included in Section 1.4. These have been examined to determine what support the Com/Nav Research Facility must provide in order to serve as a versatile experiment test facility.

The Com/Nav Research Facility will support three distinct types of activity. These activities are: (1) experimentation; (2) data processing and; (3) maintenance and troubleshooting. These three types of activity are depicted in Figure 1-1.

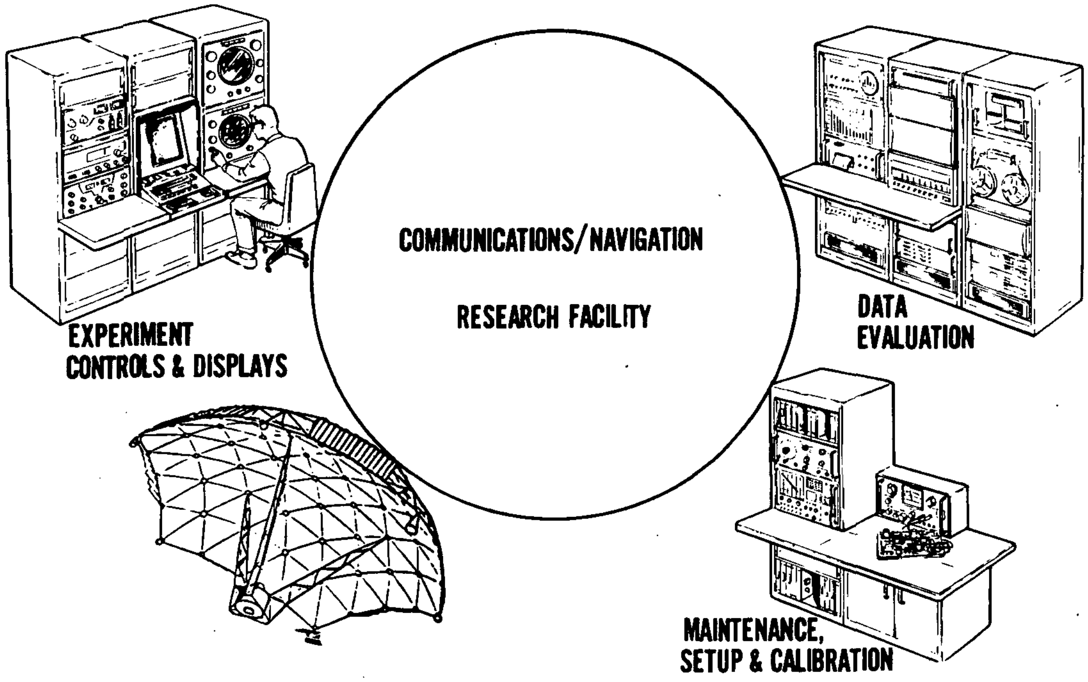


Figure 1-1. Communications/Navigation Research Facility

Several of the listed experiments require space-to-space operating modes with one terminal located in another space vehicle (such as a subsatellite) remote from the Com/Nav Research Facility. The requirements and constraints imposed upon the remote experiment terminal are specified within the experiment.

Some experiments require that certain equipments be located exterior to the Com/Nav Facility. EVA and any special requirements are included within the experiment description. A large parabolic expandable truss antenna (PETA) similar to that in Figures 1-2 and 1-3 is an example of such an item of equipment. The antenna is shown in folded (Figure 1-2) and open (Figure 1-3) positions.

Table 1-1 summarizes in a matrix the equipment for a "core" facility to support all of the listed experiments. Equipment items listed are considered as the "core" of the research facility. They are presented in two categories: (1) Standard test equipment and (2) Experiment equipments that are common to a number of experiments and thus retained as part of the "core". Table 1-2 lists the equipment classified as "experiment peculiar". Table 1-2 lists experiment-peculiar equipment in common classes but not identical items. For example, a receiver input module is used for several experiments; however, this module will, in general, be selected for a particular experiment to give the desired frequency coverage, bandwidth and perhaps other

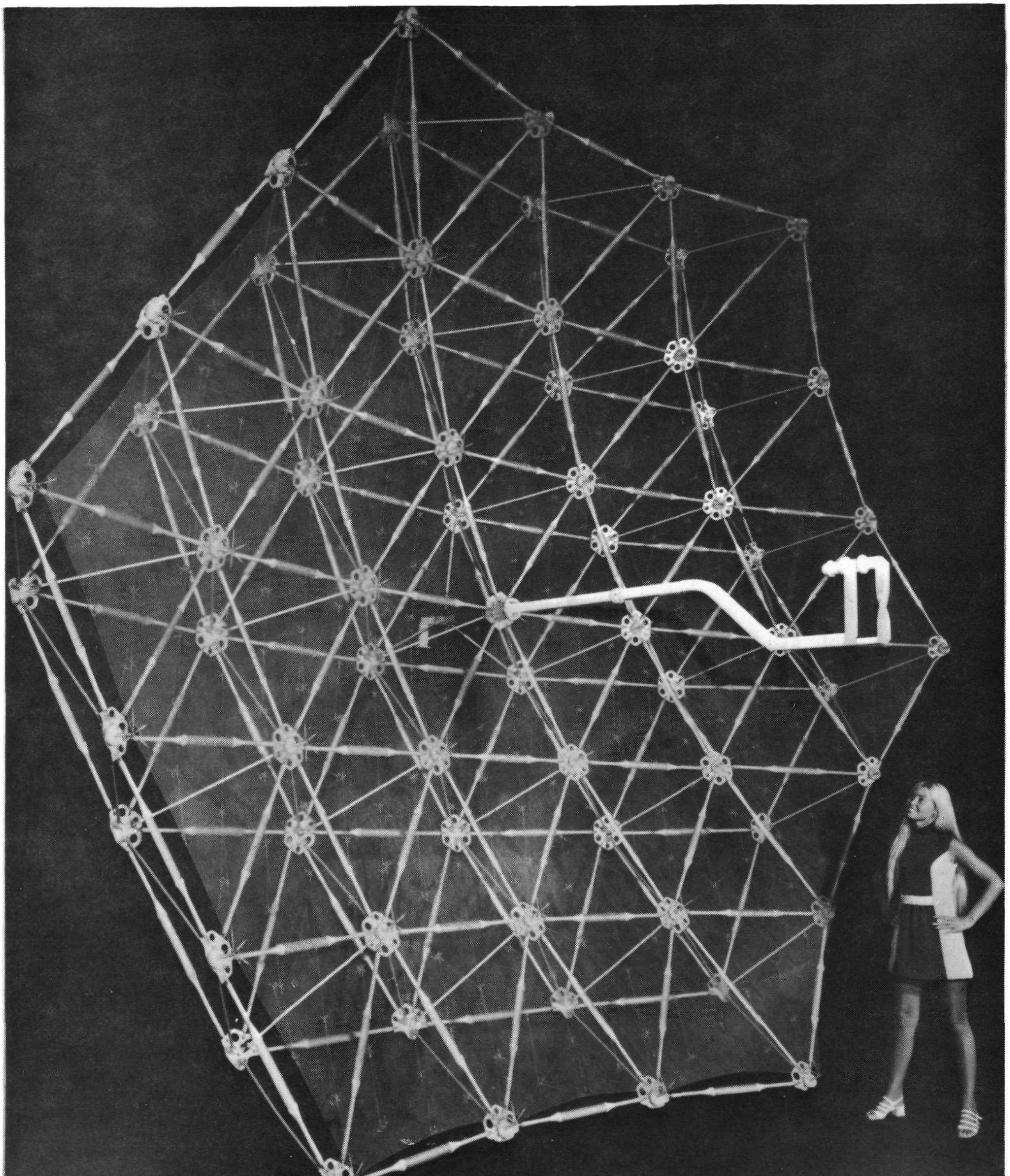


Figure 1-2. Open Parabolic Expandable Truss Antenna (PETA)

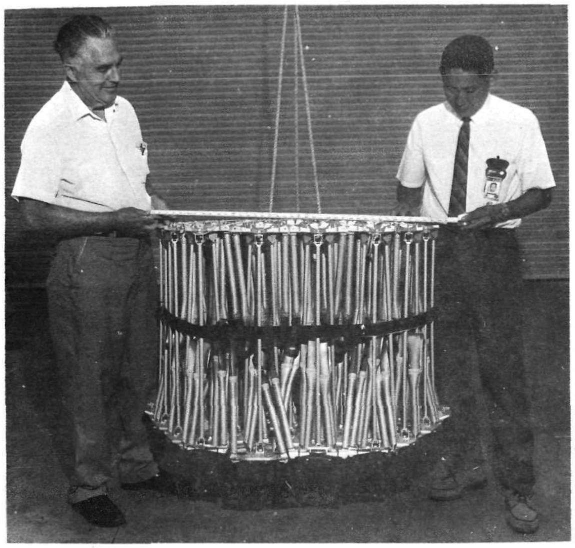


Figure 1-3. Folded Parabolic Expandable Truss Antenna (PETA)

characteristics. Supporting data (mass, volume, etc.) describing the "core" equipment is presented in Table 1-3.

1.3 EXPERIMENT REQUIREMENTS SUMMARY

The 13 typical experiments are listed in Table 1-4, and the individual requirements of each experiment are summarized. The table indicates several instances in which a subsatellite may be employed. Recognizing that this complicates an experiment, the cases in point are explained:

a. Experiments 1.4.1 and 1.4.2 have significant facility-to-ground modes. The facility-to-space modes, while desirable, are not essential to make the experiments of value.

b. If the fullest benefit is to be derived from Experiments 1.4.3 and 1.4.4, a second space terminal is desirable. Reexamination of experiment goals is required if the second space vehicle is not available.

c. Experiments 1.4.5, 1.4.12 and 1.4.13 require the use of a second space vehicle or subsatellite.

Table 1-1. Standard C/NRF Support Facility Items

				Standard Test Equipment Inventory												Common Experiment Equipments & Associated Items																						
Experiment Number and Title 1.4. n		Voice Communication to Ground	Telemetry Link to Ground	DC Voltmeter (Possibly Digital)	DC Ammeter (Possibly Clamp-On)	AC Voltmeter	Multimeter, 20 Hz - 700 MHz	Power Meter, Thermistor & Xtal Inputs	Oscilloscope, 50 MHz, 0.1 μsec/cm	Wideband Spectrum Analyzer, 10 MHz-40GHz	μ Wave & mm Wave Noise Generators	VSWR Meter	Frequency Counters	Function Generator	Calibrated Waveguide & Coax Std's	RF Receiver, Common Blocks	RF Transmitter, Common Blocks	Modulator (Amplitude, Freq., Phase)	Demodulator (Amplitude, Freq., Phase)	Data Processor, Common Blocks	Clock, Synch. or Reference Synthesis	Multiplexer/Demultiplexer	Analog-to-Digital/Dig-to-Analog	Encoder/Decoder	General Purpose Onboard Computer	Bit Error Counter	9 m (29.8 ft) Diameter Space Erectable Antenna	Changeable Feeds, Transmission Lines for Wideband Coverage	Antenna Tracking System	Antenna Position Readout	Ensemble of Dipole Arrays, Aperture, Log-Periodic and Spiral Antennas	Boresight Telescope	Ephemeris Data Presentation	C/NRF Integrated Attitude Control	Analog Recorder (10 Channel)	Narrowband Recorder	Wideband Recorder	35 or 70 mm Camera
n		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
1	Optical Communications & Propagation	●	●	●	●	●	●		●	●				●				●	●	●	●	●	●	●		●						●	●	●	●	●		●
2	mm Wave Communications & Propagation	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●			●	●	●	●	●	●	●	●		●
3	Surveillance, Search & Rescue	●	●	●	●	●	●	●	●	●	●	●	●	●	●																●		●		●		●	
4	Sat. Nav. Technique for Terr. Users	●	●	●	●	●	●	●	●	●	●	●	●	●	●					●	●	●	●	●	●	●					●		●	●	●	●		
5	Onboard Laser Ranging	●		●	●	●	●		●	●				●				●	●	●	●		●		●	●						●	●	●	●		●	●
6	Autonomous Space Navigation	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●		●	●	●				●	●	●		●	●	●		●	
7	Transmitter Breakdown	●		●	●	●	●	●	●	●		●		●			●	●													●				●			●
8	Terrestrial Noise in Space	●		●	●	●	●		●	●			●	●	●	●				●			●	●			●	●	●	●	●		●	●	●		●	
9	Noise Source Identification	●	●	●	●	●	●		●	●	●		●	●	●	●			●	●			●	●	●		●	●	●	●	●	●	●	●	●		●	
10	Interference From Sat. Trans.	●		●	●	●	●	●	●	●	●	●		●			●	●		●					●		●	●	●	●	●	●	●	●	●			
11	Tropospheric Propagation	●	●	●	●	●	●		●	●	●		●	●	●	●				●	●		●	●	●		●	●	●	●	●	●	●	●	●		●	●
12	Plasma Propagation	●		●	●	●	●		●	●	●		●	●	●	●				●			●	●		●			●	●	●		●	●	●		●	
13	Multipath Measurements	●	●	●	●	●	●	●	●	●		●	●	●	●		●	●		●									●	●	●		●	●	●			

Table 1-2. Experiment Peculiar Equipment

		Transmitters				Receivers					Special Purpose Equip. and Subsystems												
Experiment Number and Title 1.4. n		RF, Experiment Peculiar Blocks	RF, Auxiliary Acquisition	Optical	Optical, Auxiliary Acquisition	RF, Experiment Peculiar Blocks	RF, Auxiliary Acquisition	Radiometer Calibrator	Optical	Optical, Auxiliary Acquisition	Data Processor, Peculiar Blocks	Modulator, Peculiar Blocks	Laser Tracking System, Readout & Record	Sensors, Electromagnetic	Sensors, Inertial	Instrument Probes: Optical, Plasma, Pressure, Temp; Mass Spectrometer	Star Tracker	Television Mapping	IR Cold Body Tracker	IR Horizon Scanner	Communication to Deep Space Probe	Transponder	Subsatellite
n		38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
1	Optical Communications & Propagation			●	●				●	●	●	●	●								●		●
2	mm Wave Communications & Propagation	●	●			●	●				●	●									●		●
3	Surveillance, Search & Rescue																					●	●
4	Sat. Nav. Technique for Terr. Users										●											●	●
5	On Board Laser Ranging			●	●				●	●	●	●	●										●
6	Autonomous Space Navigation	●		●		●			●		●			●	●		●	●	●	●			
7	Transmitter Breakdown	●										●				●							
8	Terrestrial Noise in Space					●		●			●												
9	Noise Source Identification					●					●												
10	Interference From Sat. Trans.	●									●	●											
11	Tropospheric Propagation					●					●												
12	Plasma Propagation					●					●												●
13	Multipath Measurements	●									●	●											●

Table 1-3. Standard "Core" Support Facility Items
(Reference Table 1-1 for identity of items)

ITEM NO.	MASS kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER (watts)
1	-	-	-	-
2	-	-	-	-
3	8.2 (18)	0.017 (0.6)	0.26×0.26×0.26 (0.84×0.84×0.84)	30
4	0.9 (2)	0.0008 (0.03)	0.09×0.09×0.09 (0.3×0.3×0.3)	-
5	0.5 (1)	0.0003 (0.008)	0.01×0.01×0.01 (0.2×0.2×0.2)	-
6	3.6 (8)	0.006 (0.2)	0.08×0.08×0.08 (0.3×0.3×0.3)	20
7	2.7 (6)	0.006 (0.2)	0.08×0.08×0.08 (0.3×0.3×0.3)	2
8	14.5 (32)	0.028 (1.0)	0.3×0.3×0.3 (1.0×1.0×1.0)	92
9	40 (88)	0.059 (2.1)	0.4×0.4×0.4 (1.3×1.3×1.3)	275
10	2.7 (6)	0.0085 (0.3)	0.2×0.2×0.2× (0.7×0.7×0.7)	10
11	4.1 (9)	0.0085 (0.3)	0.2×0.2×0.2 (0.7×0.7×0.7)	1
12	14.5 (32)	0.025 (0.9)	0.3×0.3×0.3 (1.0×1.0×1.0)	150
13	9.1 (20)	0.017 (0.6)	0.26×0.26×0.26 (0.84×0.84×0.84)	25
14	9.1 (20)	0.028 (1.0)	0.3×0.3×0.3 (1.0×1.0×1.0)	-
15	3.2 (7)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10
16	6.8 (15)	0.028 (1.0)	0.3×0.3×0.3 (1.0×1.0×1.0)	30
17	6.8 (15)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	20
18	3.6 (8)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10

Table 1-3. Standard "Core" Support Facility Items (Continued)

ITEM NO.	MASS kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER (watts)
19	3.6 (8)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10
20	9.1 (20)	0.017 (0.6)	0.26×0.26×0.26 (0.84×0.84×0.84)	25
21	9.1 (20)	0.017 (0.6)	0.26×0.26×0.26 (0.84×0.84×0.84)	25
22	9.1 (20)	0.017 (0.6)	0.26×0.26×0.26 (0.84×0.84×0.84)	25
23	9.1 (20)	0.017 (0.6)	0.26×0.26×0.26× (0.84×0.84×0.84)	25
24	3.6 (8)	0.003 (0.1)	0.14×0.14×0.14 (0.5×0.5×0.5)	25
25	13.6 (30)	0.04 (1.4)	0.34×0.34×0.34 (.1.×1.1×1.1)	50
26 Folded	32 (70)	1.3 (47)	1.4 × 0.9L (4.5D × 3L)	-
27	4.5 (10)	0.057 (2)	0.4×0.4×0.4 (1.3×1.3×1.3)	-
28	22.7 (50)	0.057 (2)	0.4×0.4×0.4 (1.3×1.3×1.3)	100
29	2.3 (5)	0.028 (1)	0.3×0.3×0.3 (1.0×1.0×1.0)	25
30	-	-	-	-
31	2.3 (5)	0.0005 (0.19)	0.12D × 0.46L (0.4D × 1.5L)	-
32	-	-	-	-
33	-	-	-	-
34	22.7 (50)	0.034 (1.2)	0.32×0.32×0.32 (1.1×1.1×1.1)	500
35	22.7 (50)	0.04 (1.4)	0.34×0.34×0.34 (1.1×1.1×1.1)	80
36	45.1 (100)	0.11 (3.8)	0.48×0.48×0.48 (1.6×1.6×1.6)	250
37	2.3 (5)	0.004 (0.13)	0.16×0.16×0.16 (0.5×0.5×0.5)	-
SUM	344 (760)	2.19 (77.3)	1.3×1.3×1.3 (4.3×4.3×4.3)	1815

Table 1-4. Communications/Navigation Experiment Requirements Summary

EXPERIMENT	MASS (WEIGHT) kg	(lb)	VOLUME m³	(ft³)	ENVELOPE m (ft)	POWER REQUIREMENTS* watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
1.4.1 Optical Frequency Demonstration							Electronic Engineer Optical Technician	None	Setup: 3 hr. Operation Cycle: Facility to ground. 10 min/orbit/Gnd.Sta. Facility to Sat. 60 min/conjunction. Facility to deep space. Up to 90 min/orbit. Data evaluation: Approx. same as ops cycle Maintenance: As needed Total Time: One month of each season for one year	Real Time: 30 kbs Onboard storage (while collecting data): One 370 m (1200 ft) reel of mag.tape/orbit 10 cloud photos/orbit	Pointing Direction: Earth Pointing Accuracy: 0.000175 rad (0.01°) to 0.000873 rad (0.05°). Pointing Drift Rate Limit: 0.0175 rad (1°) per second	Altitude: 185 km (100 n.mi.) to 556 km (300 n.mi.) Inclination: Maximum - Polar (desired) Minimum - 0.49 rad (28°).	Subsatellite requires means of launching. Crew eye protection while operating. This is an inclination-dependent experiment.
Laser Receiver	6.8	(15)	0.057	(2)	0.39×0.39×0.39 (1.26×1.26×1.26)	10 Thermal Load: 10 W							
Laser Transmitter	11.3	(25)	0.057	(2)	0.39×0.39×0.39 (1.26×1.26×1.26)	300 Thermal Load: 300 W							
Processor	3.2	(7)	0.014	(0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load: 10 W							
1.4.2 Millimeter Wave Communication and Propagation System							Electronic Engineer Microwave Specialist	None	Setup: 3 hr Operation Cycle: Facility to Gnd. 10 min/orbit/Gnd.Sta. Facility to Sat.. 60 min/conjunction Facility to deep space. Up to 90 min/orbit. Data Evaluation: Approx. same as ops cycle. Maintenance: As needed. Total Time: One month of each season for one year.	RealTime. 30 kbs Onboard storage (while collecting data): One 370 m (1200 ft) reel of mag. tape/orbit 10 cloud photos/orbit	Pointing Direction: Earth Pointing Accuracy: max. error - 0.0175 rad (1°) Pointing Drift Rate Limit: 0.0175 rad (1°) per second	Altitude: 185 km (100 n.mi.) to 556 km (300 n.mi.) Inclination: Maximum - Polar (desired) Minimum - 0.49 rad (28°).	Subsatellite requires means of launching. EVA for antenna feed change possibly required. This is an inclination-dependent experiment.
Receiver	3.6	(8)	0.014	(0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load: 10 W							
Transmitter	6.8	(15)	0.028	(1)	0.3×0.3×0.3 (1.0×1.0×1.0)	30 Thermal Load 24 W							
Processor	3.2	(7)	0.014	(0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load 10 W							
Antenna, 1m (3.3 ft) D. parabola.	5.5	(12)	Nominally 0.24	(8.5)	1 (3.3) diam. × 0.3 (1.0) depth	N.A.							
1.4.3 Surveillance and Search and Rescue Systems Demonstration							Electronic Engineer Microwave Specialist	None	Setup: 2 hr Operation Cycle: 10 min/orbit/gnd. sta. Data Evaluation: Approx. same as ops cycle. Maintenance: As needed. Total Time: One month	Real Time: Max. 300 kbs Min. 100 kbs Onboard storage: One 370 m (1200 ft) reel mag. tape/orbit when operating in a store-and-process-onboard mode.	Pointing Direction: Earth Pointing Accuracy: Max. error - 0.0175 rad (1°) Pointing Drift Rate Limit: 0.0175 rad (1°) per sec.	Altitude: 185 km (100 n.mi.) to 556 km (300 n.mi.). Inclination: Maximum - Polar Minimum - 0.49 rad (28°).	Subsatellite possible (will require means for launch). Availability of ship or aircraft user and ground radar tracking is related to inclination.
Transponder	11.3	(25)	0.028	(1)	0.3×0.3×0.3 (1.0×1.0×1.0)	40 Thermal Load 36 W							
Antennas (2 or 3 possibly inflatable conical spirals)	1.4	(3)	0.028 Stowed	(1)	0.3×0.3×0.3 (1.0×1.0×1.0), stowed.**	N.A.							

*Primary power level continuous during data collection. **Nominally 1/3 to 1 m base diam. and 1/3 to 1 m height (1.1 to 3.3 ft) each, when deployed.

Table 1-4. Communications/Navigation Experiment Requirements Summary, Contd

EXPERIMENT	MASS (WEIGHT) kg (lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS* watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
1.4.4 Satellite Navigation Techniques for Terrestrial Users					Electronic Engineer Microwave Specialist	None	Setup: 2 hr Operation Cycle: 10 min/orbit/Gnd. Sta. Data Evaluation: Approx. same as ops cycle. Maintenance: As needed Total Time: One month	Real Time: 2 kbs Onboard storage: One 370 m (1200 ft) reel mag. tape/orbit when operating in a store-and-process-onboard mode.	Pointing Direction: Earth Pointing Accuracy: 0.000175 rad (0.01°) to 0.000873 rad (0.05°). Pointing Drift Rate Limit: 0.00175 rad (0.1°). per sec	Altitude: 185 km (100 n. mi.) to 556 km (300 n. mi.). Inclination: Maximum - Polar Minimum - 0.49 rad (28°)	Subsatellite possible (will require means for launch) Availability of ship or aircraft user and ground track radar is related to inclination. Maximum stability required in interferometer mode (baseline to be determined)
Power Output Stages	15.9 (35)	0.042 (1.5)	0.35×0.35×0.35 (1.1×1.1×1.1)	100 Thermal Load 80 W							
Receiver and Transponder Electronics	6.8 (15)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	30 Thermal Load 30 W							
Clock and Code Generator	4.5 (10)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load 10 W							
Antennas (2 or 5, depending upon use of interferometer method — possibly inflatable conical spiral)	Up to 2.3 (5)	Up to 0.057 (2) stowed	Up to 0.39×0.39×0.39 (1.26×1.26×1.26) stowed.**	N.A.							
1.4.5 Onboard Laser Ranging					Electronic Engineer Optical Technician	None	Setup: 3 hr Operation Cycle: 1 hr/range run; several hours if docking. Data Evaluation: 1 hr/run Maintenance: As needed Total Time: One month or more; estimate 30 runs.	Real Time: Not Reqd Onboard storage: A-scope and camera. 10 photos per run. Record of detections for correlation with comparison radar; one 370 m (1200 ft) reel mag. tape/run (when collecting data).	Pointing Direction: Earth Pointing Accuracy: 0.000175 rad (0.01°) to 0.000873 rad (0.05°). Pointing Drift Rate Limit: 0.0175 rad (1°) per sec.	Altitude: 185 km (100 n. mi.) to 556 km (300 n. mi.). Inclination: 0.49 rad (28°) or greater	Crew eye protection while operating Subsatellite use possible (will require means for launch). Total elapsed time will depend upon availability of targets positioned to permit acquisition and ranging.
Laser Receiver	6.8 (15)	0.057 (2)	0.39×0.39×0.39 (1.26×1.26×1.26)	10 Thermal Load 10 W							
Laser Transmitter	11.3 (25)	0.057 (2)	0.39×0.39×0.39 (1.26×1.26×1.26)	300 Thermal Load 300 W							
Processor	3.2 (7)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load 10 W							
1.4.6 Autonomous Navigation Systems for Space					Electronic Engineer Electro-mechanical Technician	None	Setup: 3 hr/sensor Operation Cycle: 10 min/orbit Data Evaluation: 3 times op cycle; nominally 30 min/orbit Maintenance: As needed Total Time: 1 month/group of sensors.	Real Time: Not Reqd Onboard storage (when taking fixes): One 370 m (1200 ft) reel mag. tape/run.	Pointing Direction: Earth Pointing Accuracy: Max. error - 0.0175 rad (1°) Pointing Drift Rate Limit: 0.0175 rad (1°) per sec	Altitude: 185 km (100 n. mi.) to 556 km (300 n. mi.). Inclination: >0.49 rad (28°)	Possibility of more than 1 type sensor simultaneously. Necessity for EVA is related to sensor types used. Experiment is inclination-dependent since ground track radar confirmation is needed.
Sensors (several types possible)	2.3 (5) to 18.1 (40)	0.003 (0.2) to 0.042 (1.5)	0.14×0.14×0.14 (0.64×0.64×0.64) 0.35×0.35×0.35 (1.1×1.1×1.1)	0.5 to 20 Thermal Load 0.5 to 20 W							
Processor	3.2 (7)	0.014 (0.5)	0.8×0.8×0.8	10 Thermal Load 10 W							
Microwave Antenna (in microwave sensor mode)	5.5 (12)	0.24 (8.5)	1 (3.3) diam × 0.3 (1.0) depth***	N.A.							

*Primary power level continuous during data collection.

** Nominally 0.3 to 1 m (1.1 to 3.3 ft) diameter parabola.

***Nominally 1 m (3.3 ft) diameter parabola.

Table 1-4. Communications/Navigation Experiment Requirements Summary, Contd

EXPERIMENT	MASS (WEIGHT) kg	(lb)	VOLUME m^3	(ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS* watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
1.4.7 Transmitter Breakdown Tests							Electronic Engineer Microwave Specialist	None	Setup: 2 hr Operation Cycle: Less than 1 min/break-down Data Evaluation: 2 hours (includes examination of extra vehicular breakdown region). Maintenance: As needed Total Time: 1 week based upon 2 orbits per measurement and 10 measurements (2 frequencies, 5 altitudes).	Real Time: Not Reqd Onboard Storage (when collecting data): One 370 m (1200 ft) reel mag tape. 40 photos of feed (4 per breakdown).	Pointing Direction Stability: No requirement	Altitude: 148 km (80 n.mi.) perigee, 740 km (400 n.mi.) apogee Inclination: 0.49 rad (28°) or greater	Test altitudes: km (n.mi.) 148 (80) 296 (160) 444 (240) 592 (320) 740 (400) EVA for feed examination and change, and possibly for setup and servicing external instrumentation. Require ephemeris to know altitude. Point antenna to space during test.
Transmitter and Modulator	34	(75)	0.057	(2)	$0.38 \times 0.38 \times 0.38$ $(1.26 \times 1.26 \times 1.26)$	25 - 50 Thermal Load 20 - 40 W							
Instrumentation	9.1	(20)	0.028	(1)	$0.3 \times 0.3 \times 0.3$ $(1.0 \times 1.0 \times 1.0)$	10 Thermal Load 10 W							
1.4.8 Terrestrial Noise Measurements							Electro-mechanical Technician Microwave Specialist	None	Setup: 3 hr Operation Cycle: Continuous Data Evaluation: Continuous monitoring Maintenance: As needed Total Time: ≈ 2 yr for full coverage, based upon 10^9 bits per map of earth with 0.0175 rad (1°) antenna beam, 8 gray shades and 1 meas per 0.5 seconds.	Real Time: Not Reqd Onboard Storage: Four 370 m (1200 ft) reels mag. tape (@ 10^3 bits/inch, 20 tracks recorded in series, 0.05 m (2 in.) tape). Cloud photos for correlation with radiation temp; estimate 10/day.	Pointing Direction: Earth Pointing Accuracy: Max. error = 0.0044 rad (0.25°) Pointing Rate Limit: 0.0087 rad (0.5°) per sec.	Altitude: 185 km (100 n.mi.) to 556 km (300 n.mi.). Inclination: Max. Polar (desired) Min. 0.95 rad (55°).	EVA likely for antenna changes Polar orbit necessary for full earth map. Experiment time can be shortened significantly by reducing resolution with wider-beam antennas. Antennas listed provide 0.0175 rad (1°) beam 32 to 2.3 GHz. Beam increases to 0.3 rad (17°) at 0.136 GHz. Desire measurement of earth's surface radiation temperature for extremes of climatic condition.
Receiver & Processor (Microwave)	4.5	(10)	0.028	(1)	$0.3 \times 0.3 \times 0.3$ $(1.0 \times 1.0 \times 1.0)$	15 Thermal Load 15W							
Receiver & Processor (milli-meter wave)	4.5	(10)	0.028	(1)	$0.3 \times 0.3 \times 0.3$ $(1.0 \times 1.0 \times 1.0)$	15 Thermal Load 15 W							
Antennas, 1 m (3.3 ft) Diam. Parabola	5.5	(12)	0.24	(8.5)	1 (3.3) D × 0.3 (1.0) L	N.A.							
Expandable Antennas, Open Diameter:			Folded Volume & Envelope										
3m (9.8 ft)	7	(16)	0.05	(1.8)	0.5 D × 0.3 L (1.5 D × 1.0 L)	N.A.							
5 m (16.4 ft)	14	(30)	0.2	(7.8)	0.8 D × 0.5 L (2.5 D × 1.6 L)	N.A.							

* Primary power level continuous during data collection.

Table 1-4. Communications/Navigation Experiment Requirements Summary, Contd

EXPERIMENT	MASS (WEIGHT) kg	(lb)	VOLUME m^3	(ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS* watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
1.4.9 Noise Source Identification							Electronic Engineer Microwave Specialist	None	Setup: 3 hr Operation Cycle: Intermittent use of entire orbit. Data Evaluation: Concurrent with measurements. Maintenance: As needed Total Time: One calendar year, min.	Real Time: 10^6 bps Onboard Storage: (based upon 1/2 of experiment 5.4.1.4.8) Two 370 m (1200 ft) reels mag. tape.	Pointing Direction: Earth Pointing Accuracy: Max. error = 0.0044 rad (0.25°) Pointing Rate Limit: 0.0087 rad (0.5°) per sec.	Altitude: 185 km (100 n.mi.) to 556 km (300 n.mi.) Inclination: Max. - Polar Min. - 0.95 rad (55°).	Possibility of EVA for antenna feed change. May require prearranged energizing of noise sources on earth.
Receiver	3.6	(8)	0.014	(0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load: 10 W							
Processor	3.2	(7)	0.014	(0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load: 10 W							
1.4.10 Susceptibility of Terrestrial Systems to Satellite Radiated Energy							Electronic Engineer Microwave Specialist	None	Setup: 3 hr Operating Cycle: 1 measurement/orbit Data Evaluation: Monitoring only; data evaluation on ground. Maintenance: As needed Total Time: One month with prearranged ground stations available.	Real Time: Not Reqd Onboard storage: Experiment log sheets only with monitored power levels.	Pointing Direction: Earth Pointing Accuracy: Max. error = 0.0044 rad (0.25°). Pointing Rate Limit: 0.0087 rad (0.5°) per sec.	Altitude: 185 km (100 n.mi.) to 556 km (300 n.mi.) Inclination: Max. - Polar Min. - 0.49 rad (28°).	Possibility of EVA for antenna feed changes. Requires high degree of coordination with ground terminals to prevent interference with critical systems.
Transmitter	6.8	(15)	0.028	(1)	0.3×0.3×0.3 (1.0×1.0×1.0)	50 Thermal Load: 40 W							
Modulation Envelope Generator	3.2	(7)	0.014	(0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load: 10 W							
Antennas 1 m (3.3 ft) Diam. Parabola	5.5	(12)	0.24	(8.5)	1 D×0.3 L (3.3 D × 1 L)	N.A.							
Expandable Antennas - Open Diameter:			Folded Volume and Envelope										
3 m (9.8 ft)	7	(16)	0.05	(1.8)	0.5 D×0.3 L (1.5 D×1.0 L)	N.A.							
5 m (16.4 ft)	14	(30)	0.2	(7.8)	0.8 D×0.5 L (2.5 D×1.6 L)	N.A.							
1.4.11 Tropospheric Propagation Measurements							Electronic Engineer Microwave Specialist	None	Setup: 3 hr Operation Cycle: 10 min/orbit/ground sta. Data Evaluation: 2 to 3 times data collection time Maintenance: As needed Total Time: 1 calendar year to cover frequencies, angles of arrival and weather conditions.	Real Time: 30 kbs Onboard Storage (when collecting data): one 370 m (1200 ft) reel mag. tape/orbit. Two cloud-cover photos/orbit.	Pointing Direction: Earth Pointing Accuracy: Max. error = 0.00175 rad (0.1°) Pointing Rate Limit: 0.0087 rad (0.5°) to 0.0175 rad (1°) per second.	Altitude: 185 km (100 n.mi.) to 556 km (300 n.mi.) Inclination: Max. — Polar Min. — 0.49 rad (28°).	Possibility of EVA for antenna changes 9 m (29.8 ft) diam. antenna is predicated. Smaller antenna may be desirable at higher frequencies to ease acquisition problem Availability of ground transmitting stations is potentially a time-limiting factor.
Receiver	3.6	(8)	0.014	(0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load 10 W							
Processor	3.2	(7)	0.014	(0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load 10 W							

*Primary power level continuous during data collection.

Table 1-4. Communications/Navigation Experiment Requirements Summary, Contd

EXPERIMENT	MASS (WEIGHT) kg	(lb)	VOLUME m^3 (ft^3)	ENVELOPE m (ft)	POWER REQUIREMENTS* watts	CREW SKILLS	ENVIRONMENT REQUIREMENTS	EXPERIMENT TIME LIMITS hours	DATA REQUIREMENTS	STABILITY AND CONTROL	ORBITAL DATA	EXPERIMENT PECULIAR REQUIREMENTS
1.4.12 Plasma Propagation Experiments						Electro-mechanical Technician Microwave Specialist	None	Setup: 3 hr Operation Cycle: 10 min/re-entry Data Evaluation: 30 minutes Maintenance: As needed Total Time: 2 months (based upon 1 re-entry per 2 days).	Real Time: Not Reqd Onboard Storage: One 3,300 m (10,800 ft) reel mag. tape per re-entry (1-2 MHz band-width).	Pointing Direction: Earth Pointing Accuracy: Max. error = 0.0175 rad (1°) Pointing Rate Limit: 0.0175 rad (1°) per second.	Altitude: 185 km (100 n.mi.) to 556 km (300 n.mi.) Inclination: 0.49 rad (28°) minimum. Availability of ground tracking of probe is required.	If subsatellite used for dual link, means of launch required. Availability of re-entry probes instrumented for transmitting is time limiting factor.
Receiver	3.6	(8)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load: 10 W							
Processor	3.2	(7)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load: 10 W							
Antennas: VHF-orthogonal log periodic dipole arrays. (Probably inflatable)	2.3	(5)	Folded 0.028 (1) Open 0.3 (10.6)	0.3×0.3×0.3 (1.0×1.0×1.0) Pyramid 1.0×1.0×1.0 (3.3×3.3×3.3)	N.A.							
SHF-orthogonally polarized horn	2.3	(5)	0.003 (0.12)	0.09×0.12×0.3 (0.3×0.4×1.0)	N.A.							
1.4.13 Multipath Measurements						Electronic Engineer Microwave Specialist	None	Setup: 3 hr Operation Cycle: 10 min/orbit/ground sta. Data Evaluation: Monitoring only; evaluation on ground. Maintenance: As needed Total Time: 2 months to 1 year	Real Time: Not Reqd Onboard Storage: Minimal; transmit power monitor and COM/NAV facility attitude, rate record.	Pointing Direction: Earth Pointing Accuracy: Max. error = 0.0175 rad (1°) Pointing Rate Limit: 0.0175 rad (1°) per second.	Altitude: 185 km (100 n.mi.) to 556 km (300 n.mi.) Inclination: Max. - Polar Min. - 0.49 rad (28°)	Requires passage over water, various types of terrain, and air traffic corridors or requires aircraft dedicated for earth terminal measurements.
Transmitter	6.8	(15)	0.028 (1)	0.3×0.3×0.3 (1.0×1.0×1.0)	30 Thermal Load: 24 W							
Processor (Modulator)	3.2	(7)	0.014 (0.5)	0.24×0.24×0.24 (0.8×0.8×0.8)	10 Thermal Load: 10 W							
Antennas: VHF-orthogonal log periodic dipole arrays (probably inflatable)	2.3	(5)	Folded 0.028 (1) Open	0.3×0.3×0.3 (1.0×1.0×1.0) Pyramid 1.0×1.0×1.0 (3.3×3.3×3.3)	N.A.							
SHF - orthogonally polarized horn	2.3	(5)	0.003 (0.12)	0.09×0.12×0.3 (0.3×0.4×1.0)	N.A.							

*Primary power level continuous during data collection.

1.4 COMMUNICATIONS/NAVIGATION EXPERIMENT PROGRAM

The Communications/Navigation Research Facility has been derived by accommodating the 13 typical experiments in this FPE. A detailed discussion of each experiment is included in this section. The experiments are:

a. 1.4.1 Optical Frequency Demonstration.

b. 1.4.2 Millimeter Wave Communication System and Propagation Demonstration.

c. 1.4.3 Surveillance and Search and Rescue Systems Demonstration.

d. 1.4.4 Satellite Navigation Techniques for Terrestrial Users.

e. 1.4.5 On Board Laser Ranging.

f. 1.4.6 Autonomous Navigation Systems for Space.

g. 1.4.7 Transmitter Breakdown Tests.

h. 1.4.8 Terrestrial Noise Measurements.

i. 1.4.9 Noise Source Identification.

j. 1.4.10 Susceptibility of Terrestrial Systems to Satellite Radiated Energy.

k. 1.4.11 Tropospheric Propagation Measurements.

l. 1.4.12 Plasma Propagation Measurements.

m. 1.4.13 Multipath Measurements.

1.4.1 OPTICAL FREQUENCY DEMONSTRATION

1.4.1.1 Experiment Objective. The purpose of this experiment is to refine and extend the knowledge and range of data associated with the use of optical frequencies in space communications application. Missions encompassed are space-to-ground, space-to-space, and deep-space (~1 A.U.) to relay.

1.4.1.2 Experiment Description. This experiment consists of two parts. The first is the space-to-ground link and the second is the space-to-space link. The primary distinction is the intervention of the Earth's atmosphere in the former link. It is convenient to consider two features of laser communication links which stem from the narrow beamwidths that are easily attainable. In space-to-ground links this means that a high order of beam "footprint" control can be obtained. On the space-to-space link, the large gain of optical antennas can provide a good source of margin. It is also to be recognized that both these features require solving the problem of beam pointing.

It is inappropriate at this time to describe this experiment in terms of specific laser oscillators since this technical area is in a state of rapid change. Instead, the approach is taken of using selected wavelength regions which exhibit behavior typical of systems requirements. This general rule will also be followed with regard to the other components, although in some cases specific alternatives can be identified.

The equipment and facilities for this experiment are in part different from those used in many of the experiments using lower frequencies. Several laser oscillators (see following section for wavelength choices) will be required. It seems possible at this time to employ a common modulating element (lithium niobate or tantalate) for the wavelength range of 400 nm to 1200 nm. This represents some compromise, at least in terms of being capable of providing all alternative modulation techniques by itself. For example, additional equipment would be needed if left and right circular polarization modulation were employed. Figure 1-4 shows a mode-locked laser transmitter for PCM.

Electronic equipment must provide both wideband analog and high-data-rate digital modulations. Fairly conventional demodulation electronics should be employable in the analog case, but the digital modules will have to provide for data formatting, demultiplexing, D/A conversion and synchronization. Figure 1-5 shows a typical block diagram.

The photodetector is another area where the general alternatives are clear but specific identification is difficult. As a current baseline, it is not likely that heterodyne detection will be practical at wavelengths much shorter than about 3 μm, as shown in Figure 1-6. At the other extremity, photoemissive detectors with electron multiplication will for some time be limited to operate at wavelengths shorter than 2 μm. Solid state detectors such as Schottky barrier devices may fill the gap, and perhaps provide a broader range of alternatives.

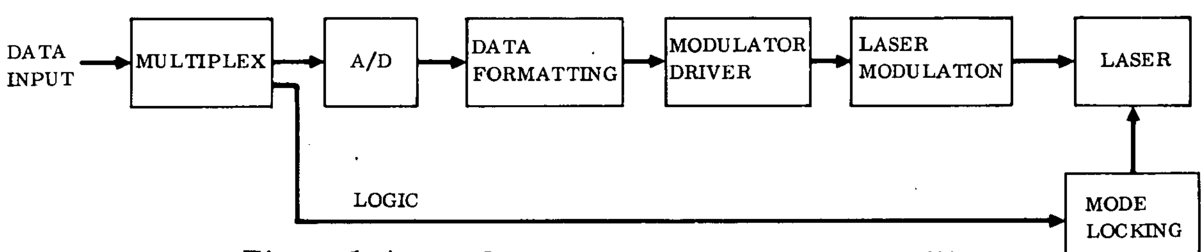


Figure 1-4. Mode-Locked PCM Laser Transmitter

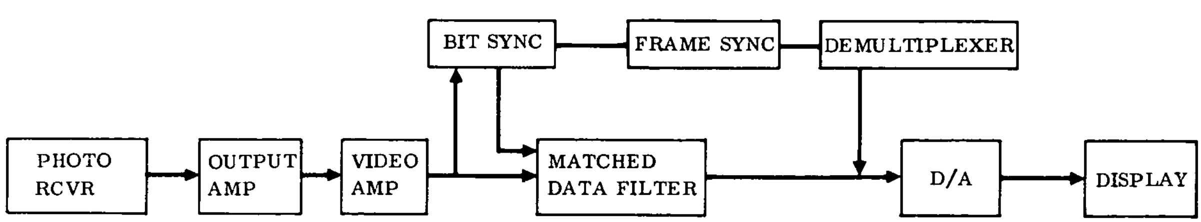


Figure 1-5. RCM Direct Detection Receiver

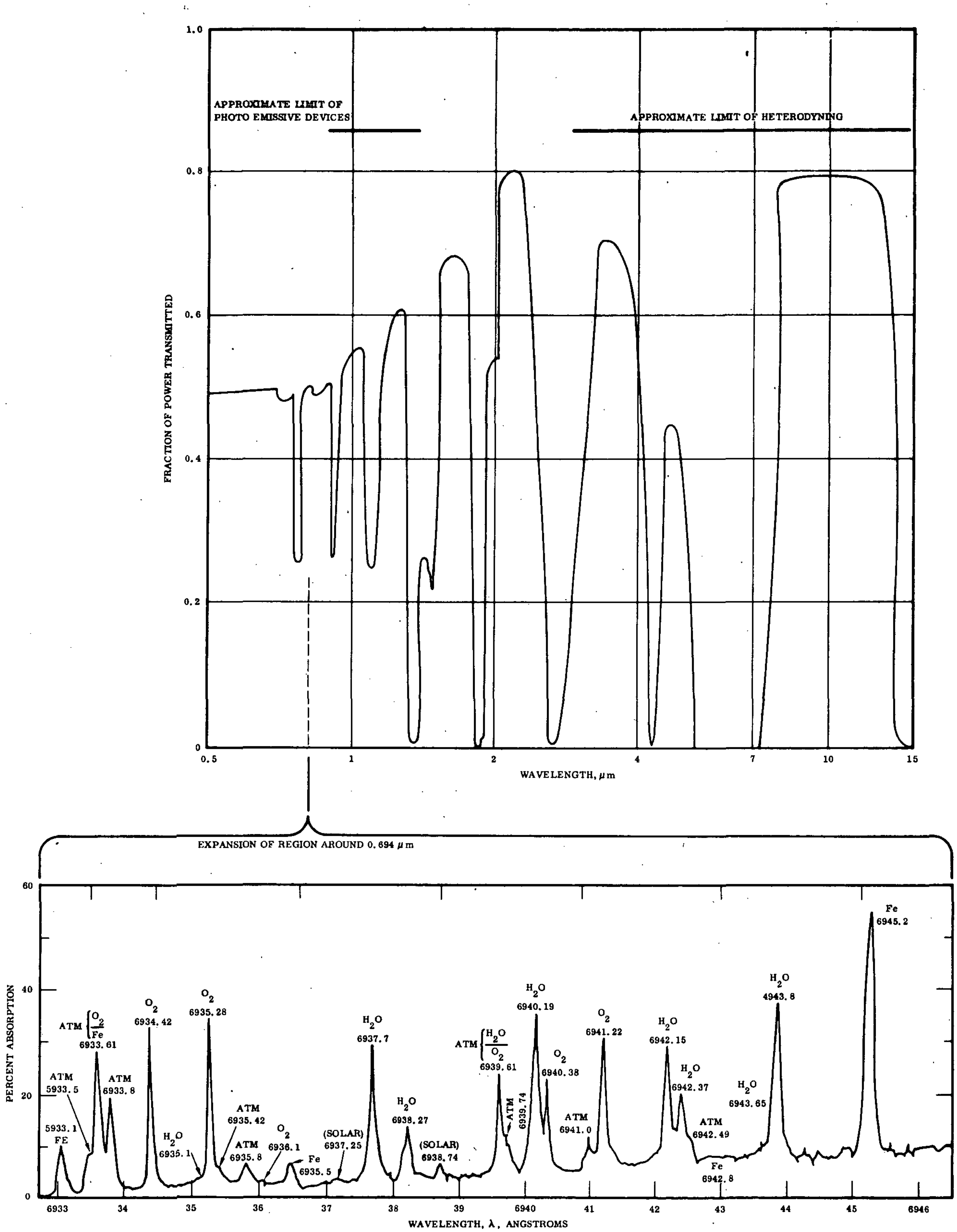


Figure 1-6. Typical Atmospheric Transmission in a 5 km Path Near Earth Surface

The optical elements comprise the most well defined components. Transmitting and receiving optical systems no greater than 30 cm to 60 cm in diameter should be adequate for the entire range of experiments. Other optical components, such as transfer lenses, optical spectral filters, beam splitters, and means for obtaining protection from the solar flux are also required; presently available devices, except for perhaps the filters, appear adequate.

A critically important subsystem is that which provides for acquisition and generation of tracking error correction signals. This will probably use a separate opto-electronic system of very modest size.

Since both space-ground and space-space links are included in the experiment objectives, it is reasonable to provide both transmitting and receiving equipment on-board the spacecraft. In some cases the transmitting source might be Earth-based.

Because existing planning calls for use of a heterodyne receiver at 10.6 μm wavelength, the problem of frequency acquisition in the presence of doppler shifts has not been discussed.

1.4.1.3 Observation/Measurement Program. For space-ground observations, the critical variables are those associated with the frequency dependence of the transmission of the Earth's atmosphere. Figure 1-6 shows both the low spectral resolution and high resolution transmission for a horizontal path near the Earth's surface. Clearly, for laser communication, knowledge such as shown in the high resolution response is essential if reasonable estimates of power budgets are to be made. It seems premature to expect from this experiment the level of statistical data on atmospheric properties such as exist at VHF. It is important, however, to relate S/N, data rates, and accuracy to determine whether classical or quantum communications theory applies at optical frequencies.

Frequency regions for these measurements should consist of at least 0.450 μm, 0.650 μm, and 1 μm. In addition to the absorbing properties of the atmosphere, the measurements should also include the effects of refractive index fluctuations on the maintenance of the desired beam pointing angle and beam width. These are essentially angle of arrival measurements.

For Part II, the space-to-space link, there are no propagation problems. However, there are background radiation problems as well as the acquisition and tracking problem.

1.4.1.4 Interface, Support and Performance Requirements. These features for this experiment are similar to those of the communication and propagation measurements

in the lower frequency range. Because it is anticipated that many of the experiments will be performed in the visible or near-visible spectral regions, it is possible to conceive of maintaining the entire optical system within the spacecraft. This possibility must be tempered by vehicle interfaces such as provision of a "window" with acceptable viewing angle constraints and possible interference with crew activities. If the optical package is mounted outside the spacecraft, then other interfaces are important. Among these are protection of the receiving system from the direct solar flux, and protection of the optical system from solar-produced thermal gradients.

Because acquisition and pointing are so critical for this experiment, the spacecraft attitude and associated rates will be required inputs to the optical tracking subsystem.

Optical modulators can be sources of RFI, so this interface should be given consideration. In the space-ground link, the illuminated Earth will be a source of background interference for the spaceborne optical receivers. However, this information is necessary for a complete understanding of performance requirements.

Because a considerable amount of data reduction is performed in the spacecraft, in the form of recording of signal level and scintillation effects, the real-time data rate for telemetry is modest. A link in the 30-kilobit/second range should be adequate.

An important interface in this experiment is that of planning the experiment so that eye damage to the crew can not occur. Lasers operating in the visible and near-visible region at flux levels greater than a few milliwatts can all be hazardous. Such flux levels can easily be/attained as a result of specular reflection of a laser beam. An exception is when the laser output is in the 1.5 μm - 1.6 μm region. Such outputs are representative of the erbium ion in various host materials (YAG or glass). In this spectral region the liquid within the eye is highly absorbing and so the thermal "load" resulting from laser exposure is dissipated in a relatively large volume so that tissue-damaging temperatures are not reached. This wavelength range is not very desirable for communication purposes. The best approach is for the crew to be fitted with protective glasses.

1.4.1.5 Potential Role of Man. Configuration changes of both optical and electronic components will probably be an important part of the experiment. Further, since relatively little can be categorized as "known" about the reliability, lifetime, and behavior of optical communications components in the space environment, the participation of the crew is a key factor in success of the experiment.

1.4.1.6 Available Background Data

W. K. Pratt, Laser Communication Systems, Wiley 1969.

1.4.2 MILLIMETER WAVE COMMUNICATION SYSTEM AND PROPAGATION DEMONSTRATION

1.4.2.1 Experiment Objectives. The general objectives of this experiment are to provide baseline data to determine the utility of employing millimeter waves in space communications applications. The experiment will provide for the collection of data on propagation between space vehicles and between an orbiting vehicle and an Earth terminal. These objectives will be met through testing of techniques and components as well as by system demonstration. Within these rather broadly defined objectives the following may be delineated:

a. Provide a realistic environment for the evaluation of millimeter wave system components such as sources and antennas. For millimeter frequencies perhaps the most critical problem is the one of acquiring and tracking narrow antenna beams. A primary goal of this experiment is to provide data on the performance of various techniques for accomplishing this.

b. Provide a means of evaluation of the propagation medium. Both attenuation and phase effects must be evaluated. In addition, the utility of space diversity of Earth-based receivers must be determined. Space diversity here refers to the use of more than one receiving terminal on Earth and requires determination of the probability that a station removed by a given number of miles from another station is occluded by tropospheric weather. In addition to such fairly conventional propagation measurements, there is at least one peculiar measurement associated with the millimeter wave range. This is the case of space-to-space propagation where the path is parallel to a tangent to the Earth's surface and lies marginally within Earth's atmosphere (93 km or 50 n.mi.). At frequencies where such a link might be employed, it is important to determine the detectability of energy scattered out of the beam to an unauthorized receiver. The regions around 60 GHz and 75 GHz are primary candidates for such a link.

c. Provide for system demonstrations. The communication opportunities for space systems employing millimeter wave frequencies are of importance. These include the wideband (high data rate) space-to-space link including terminals on both a data relay satellite and possibly also from a deep-space probe, as well as communication with one or more Earth terminals from an orbital vehicle. The objectives of this experiment provide for obtaining the backup data to engage in such system demonstrations as well for establishing the facility to provide the demonstration themselves.

1.4.2.2 Experiment Description. This experiment involves the use of transmitters and receivers in the millimeter wave region. The spaceborne facility will contain the necessary millimeter sources and receivers so that all phases of the experiment can be performed. The antenna system will be deployable from the outside of the space vehicle although it is possible that additional antennas might be contained inside the space vehicle for deployment by crew members as the need arises. A gimballed

antenna mount should be provided that can accept all antenna alternatives for both space-to-space experiments, where high precision tracking is required, and space-to-ground experiments where tracking is also required but to a lower degree of accuracy. General purpose equipment such as broadband and narrowband recorders, diagnostic equipment such as oscilloscopes and spectrum analyzers, and other laboratory test equipment are assumed to be available. Because the antenna-pointing aspect of millimeter wave technology is so critical, it might be useful to provide a special aiming telescope, boresighted permanently with the antenna mount, as an aid to acquiring terrestrial receiving terminals. Special equipment such as millimeter noise sources would also be required for the purpose of receiver calibration. It would be very useful to have simultaneous photographs of weather patterns in the neighborhood of terrestrial receiving terminals, and those might be obtained using such an optical telescope.

For convenience, the measurement program is described in two parts. The first part covers the cases of space-to-ground and the tangential links where the choice of frequency is much more important since the Earth's atmosphere within the millimeter wavelength range is highly variable in its attenuating properties. The nominal dependence of the transmission on the atmosphere is now well known. The measurements here are designed to provide more detailed data which system designers can use when it is important to know the percentage of time when a certain propagation path will exhibit useful transmission for a given frequency. For this reason the measurements must include varying the frequency within the range 30 GHz to 300 GHz. Further, for this case, ground stations must be provided in various geographical locations so that the possibility of employing space diversity can be evaluated as a means of surmounting the large attenuations in the case of rain or other precipitation. A further requirement for these measurements is for ground stations to provide elevation angle variation from vertical down to about 0.087 rad (5°). The carrier-to-noise level mentioned in the case of the space-to-space link is also a desirable quantity to measure in this case. However, because of the presence of atmospheric absorption from some carrier frequencies, it is also required that additional quantities be measured; foremost among these is the data rate. For example, it is to be expected that at some frequencies the phase distortion and the resulting intersymbol interference which results from atmospheric attenuation will limit the data rate in space-to-ground links.

The second part is that associated with space-to-space links. The specific case of the so-called tangential link has been discussed with the space-to-ground links in Part 1. For these propagation paths the primary variables of interest are antenna beam width and the appropriate set of variables associated with the hardware (source frequency and amplitude jitter, receiver noise). The hardware parameters are reliability, lifetime, response to the space environments, and compatibility with the other space vehicle interfaces. The measurement program will consist of monitoring the signal-to-noise ratio, determining probability of bit error as a function of propagation path length, and determining the dependence of the bit-error rate upon the

relative line-of-sight velocity between source and receiver. Such measurements can conveniently be made if the two space vehicles are in different orbits. If a geostationary transmitting satellite were employed then path-length variations could be very small. But to obtain data for a wide range of evaluations would require nearly world-wide ground terminals. The data concerning propagation dependence on path length would be valuable, although it will cost more in terms of data reduction. The frequency is not a critically important variable in most space-to-space tests. It enters as a determining factor in the antenna beam width and also as a factor related to hardware availability. In these tests the most important feature to evaluate is the problem of acquisition and tracking for the narrow beam width case and also the problem of compensation for possibly large doppler frequency shifts.

1.4.2.3 Observation/Measurement Program. The experiment is accomplished by assembly and hook-up of a prescribed transmitter and receiver system. For Part 1, the prescribed system must provide for transmission and reception of signals designed to measure the intensity and time-delay modifying properties of propagation paths encompassing a range of elevation angles, weather and climatic conditions, frequencies of operation, and time of day. Such raw data, collected by the facility, can be processed onboard and/or transmitted to a terrestrial station for further processing. This latter telemetry link would be operated at a frequency known to be reliable with respect to weather effects. Onboard processing would be desirable since it would allow in situ decisions about new test configurations to be made. The availability in the facility of various modulators, duplexers, signal sources and diagnostic equipment would permit evaluation of data rate limitations resulting from beam scintillations and frequency-dependent time delays.

The problem of propagation paths which are tangential to the Earth's atmosphere is considered in Part 1 even though both transmitter and receiver are in space vehicles. This portion of the experiment requires that the antennas on the two vehicles acquire and maintain track during the experiment. The tracking errors are an important experimental result.

The block diagram of the spacecraft receiver is shown in Figure 1-7. The indicated frequencies are those corresponding to relative atmospheric windows (except for 60 GHz).

The receivers have phase lock loop (PLL) carrier trackers which produce doppler-invariant local oscillator (LO) inputs. The video processor indicated might consist of several alternatives, one of which is shown. The basic function of the video processor is the extraction and recording of the results of the experiments.

In Part 2 of this experiment the data sources and modems would be employed to obtain measures of communication efficiency in terms of the C/N, information rate, and EIRP. In this part of the experiment the facility can provide antenna beam acquisition

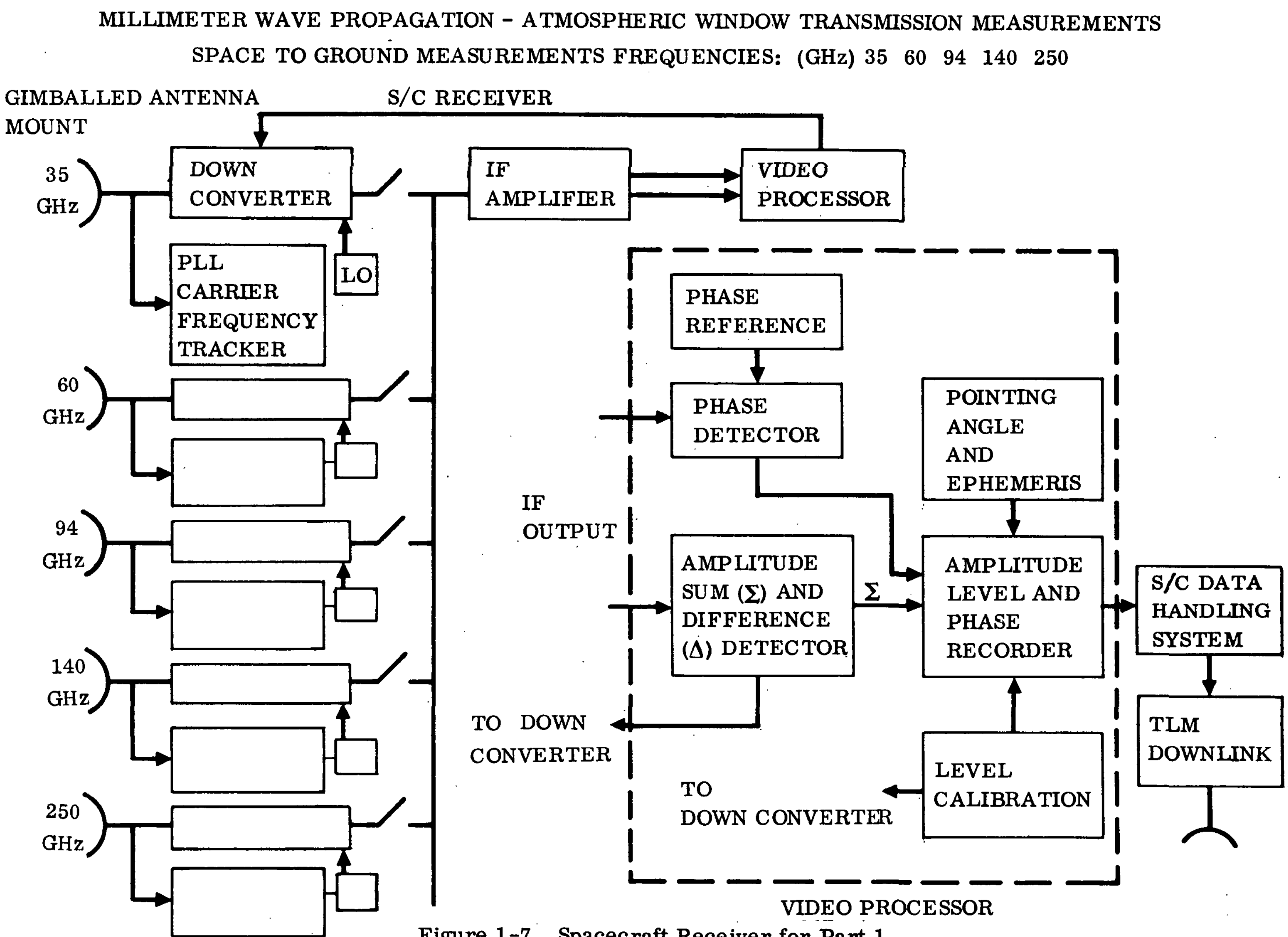


Figure 1-7. Spacecraft Receiver for Part 1

and tracking accuracy without the disturbances of an intervening absorbing and turbulent atmosphere. The data can be obtained for a variety of ranges and doppler shifts.

Only a 60 GHz transmitter is shown in the spacecraft facility (Figure 1-8). Use of this frequency has as its primary basis the evaluation of the shielding effect of the molecular oxygen in the Earth's atmosphere for a space-to-space tangential link. The wavelength of 0.005m (0.197 inches) is short enough to obtain a good measure of the antenna beam acquisition and tracking problem. Consideration should be given to a higher frequency transmitter in the space-to-space link since missions such as low orbit to synchronous or deep space links might be serviced through a millimeter wave link operating closer to 300 GHz. Component considerations are the major limiting condition here, and a specific frequency cannot be identified now. For space-to-ground measurements, transmitter operation at the window frequencies will be used.

1.4.2.4 Interface, Support and Performance Requirements. The measurements encompassed in the experiments described are all basically in the transmission-reception variety. Spacecraft attitude stabilization, particularly in space-space experiments, is important. Because the path length will be varying, ephemeris data is required input for reduction and evaluation of the data. Millimeter wave antennas are sensitive to thermal gradients because of the severe tolerances they must maintain for preservation of narrow beams. Special shrouds might be required. The data rate for the experimental data for this experiment is about 30 kilobit/sec. This modest rate results from the fact that a considerable amount of reduction is included as part of the experiment, and that experimental conditions are not expected to change very rapidly. Measurements might be made over periods of about 1 msec at 1-sec intervals. The total experiment time, however, is necessarily long. It should extend for at least one year with satellite orbit chosen to provide the broadest sample of weather and climates.

1.4.2.5 Potential Role of Man. The crew support for this experiment consists of maintenance of the equipment and reconfiguration of the equipment for the experiments. In addition, since the experiment requires gathering data over as many propagation conditions as possible, their participation is even more desirable. Familiarity with the mechanics of making antenna and front-end changes should be required. Ability to assess meteorological phenomena is desirable.

1.4.3 SURVEILLANCE AND SEARCH AND RESCUE SYSTEMS DEMONSTRATION

1.4.3.1 Experiment Objectives. Present concepts of satellite surveillance systems include an evolutionary extension of existing Air Traffic Control (ATC) networks, with ATC center still Earth-based. The satellite constellation function consists primarily of relaying position location and communication signals. For system demonstration and evaluation, the most difficult and costly aspects of the program

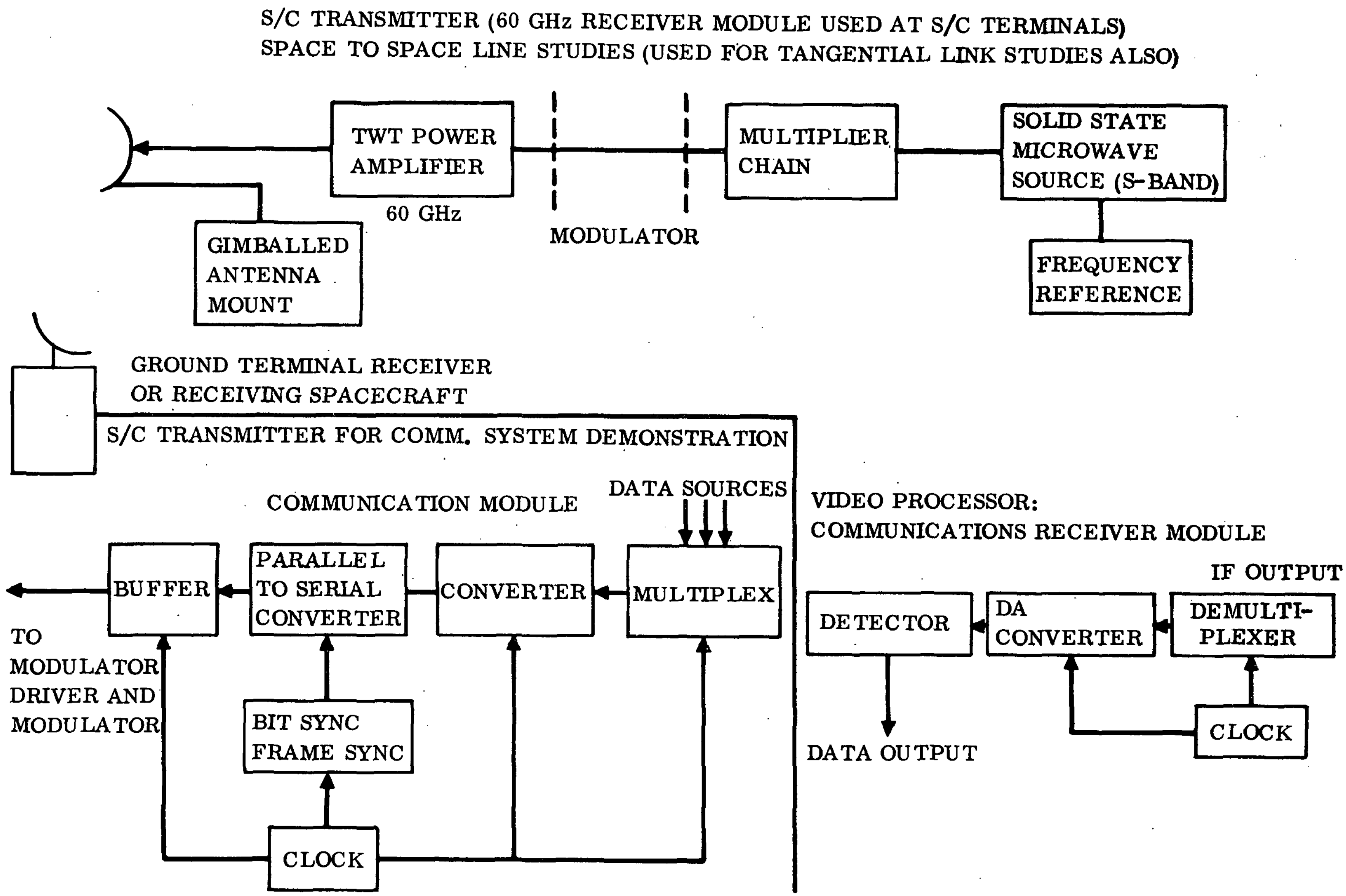


Figure 1-8. Spacecraft Transmitter and Receiver for Part II

are the creation of a realistic ground environment and the provision of satellite ground terminals. The ground environment includes both the user terminals and modification to the ATC centers for location determination and display of new position data.

Although the satellite element is not a major element of the test and evaluation costs, the system tests may be expedited by incorporation of such tests into the test requirements of an existing space facility with general purpose transponding capability. Search and rescue missions can employ operational communications satellite and navigation services. A number of satellites will probably be equipped to perform two unique services for which present capability is notably lacking, i.e., the timely detection of a distress situation, and the timely localization of an emergency location transmitter (ELT). An Earth-orbiting test program can effectively contribute data permitting system decisions which will ultimately (a) allow preparation of suitable ELT specifications, (b) require suitable ELT's to be installed on aircraft and ships, (c) place the required repeater equipment on various satellites, and (d) install the required data processing equipment in operational centers normally involved in search and rescue (i.e., military operation control centers, FAA, and USCG).

1.4.3.2 Experiment Description. The experiment consists primarily of configuring the Space Station modules as transponders at various frequencies (presently assigned frequencies include the 136 MHz, 450 MHz, 900 MHz and 1600 MHz bands). Equipment requirements include appropriate antennas, duplexer, receivers, frequency translators and transmitters for the various frequency bands. CW techniques will probably be employed, and broadband signals will undoubtedly be used. It should also be observed that present frequency allocations do not include the increased bandwidth necessary for precise position location and for the spread-spectrum approach to providing random access. Figure 1-9 is a block diagram of the transponder.

Employment of the Space Station and its modules represents a possible alternative to the use of dedicated satellites for the demonstration and test of a satellite system for terrestrial transportation vehicles. The use of hardware common to other experiments should make the satellite costs negligible, allowing most of the resources to be applied to other elements of the test.

The search and rescue experiment group consists of validating operation of spacecraft components and simulation of an operational system. When spacecraft in low orbits are employed, a store-and-forward mode of operation may be required if data processing is done on the ground. Early phases of development may include data processing and evaluation on-board, although this will not be the final mode of operation.

1.4.3.3 Observation/Measurement Program. Major problems that should receive orbital verification include: (a) determination of best frequency for detection and localization, (b) determination of the optimum feasible location method (e.g., ranging,

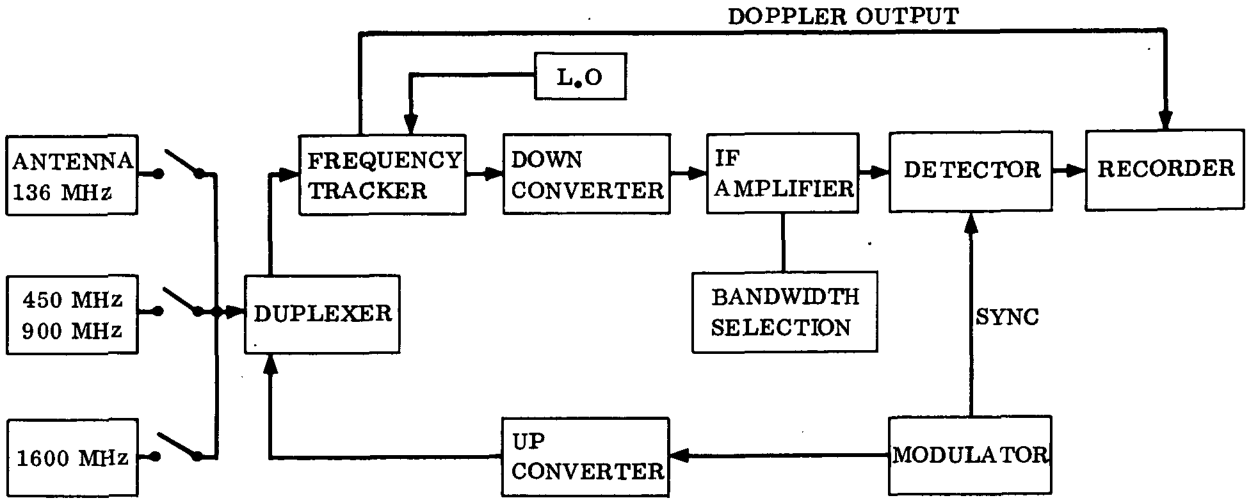


Figure 1-9. Transponder

doppler shift, or angle measured from satellite), and (c) determination of suitable modulation techniques. Reliable propagation data is very important to this experiment. One consideration in modulation techniques may be techniques which are compatible with matched filter detection design and implementation.

The detection and modulation theories appear to be adequate for the task, but verification of practical problems in implementation and measurement of performance under operational conditions is required.

A surveillance system for aircraft and marine users requires the determination of current location and velocity of all controlled vehicles, presentation to a traffic controller, and transmission of control commands back to a user. The principal observations and tests to be made in such a system include (a) accuracy attainable in line-of-sight propagation, (b) power requirements for communication ranges, and (c) accuracy available from use of high operation frequencies (L-Band) and greater available bandwidth. In the evaluation the following considerations should be included:

a. More data is displayed to a controller.

b. Higher frequencies require additional user equipment.

c. Incorporation of thousands of users into a single reliable net requires an extension of current technology.

d. The 76.3-m (250-foot) required accuracy of single fixes, although theoretically possible, is not demonstrated and user equipment as presently contemplated is relatively expensive.

The initial experiment will consist of automatic detection on the spacecraft of the signal from an emergency-location transmitter located in a suitable Earth position for satellite overflight. The signal, after detection, is then processed on-board to determine the best estimate of position. Various antennas, including interferometer arrays, may be tested for application to source location. Later tests may include location of emergency-location transmitters at unannounced locations and transponding of the receiver output to ground location for processing. Parameters for later tests will be determined by the initial test results. Such tests may include simultaneous tests with two or more emergency-location transmitters.

1.4.3.4 Interface, Support and Performance Requirements. The space-to-ground data rate required to support the experiment will be in the range of 100 kilobit/sec to 300 kilobit/sec since a synchronous satellite will not be employed in the system demonstration program. There may be an application for subsatellites, but this requirement is not firm.

Generally these experiments have only very modest demands on the spacecraft system. Orbit parameters will be chosen on the basis of evaluation use location. Measurements should include sufficient time (and locations) to provide reliable sampling of possible interferences such as propagation problems posed by severe storms, and high user densities.

1.4.3.5 Potential Role of Man. Astronaut participation in the surveillance tests will consist of configuring and setting up equipment as required and occasionally monitoring equipment for nominal operation. Some calibration activity is required. Data will be reduced and analyzed on the ground.

Astronaut operations in the search and rescue evaluation phase will include deployment and calibration of equipment, reconfiguration for other tests, monitoring the performance of relay equipment, and observing the results of on-board processing. Data is returned to Earth for ultimate system evaluation.

1.4.3.6 Available Background Data. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TRW Systems (subcontractor).

1.4.4 SATELLITE NAVIGATION TECHNIQUES FOR TERRESTRIAL USERS

1.4.4.1 Experiment Objectives. This experiment has as its primary objective the evaluation and demonstration of technology in the area of satellite navigation techniques for terrestrial users. It will provide a means of varying many of the parameters that affect the accuracy and costs of a navigation system prior to commitment to a final system configuration. It provides a demonstration vehicle for reasonably faithful simulation of operational geometry and parameter variation at substantial savings of time and money in comparison to dedicated satellites. The engineering data provided will furnish input information for system decisions.

The accuracy of navigation systems is limited by a number of error sources, some of which are well understood theoretically. The adequacy of this theoretical understanding is currently undergoing reassessment in connection with such programs as Defense Navigation Satellite (DNS). Application of special techniques such as post-detection filtering (Kalman filter) may be used for improving the accuracy. In addition, verification of theoretical analysis by experimental measurements is needed before any further meaningful development of theory can be made. System and data processing models for each technique are required. Much work is pursued in classified programs. The ultimate goal of an experimental program will be to formulate and understand a system error model of the satellite-user link which provides sufficient data and confidence to permit the deployment of a full-scale navigation satellite system. If the detailed error model of the satellite user link can be established, then the system performance can be computed and predicted in any environment.

1.4.4.2 Experiment Description. The determination of position and velocity of space vehicles by means of radio location techniques and extensive ground-based computer smoothing has been successfully and extensively employed in the guidance of ballistic missiles and in control of both automated and manned spacecraft. Basic limitations in the achievable accuracy have proven to be due to the uncertainty in our knowledge of the shape of the geoid, and to the uncertainty in the tie-ins of geodetic reference points, such as the European and North American data. The amount of smoothing required and the time required to obtain a fix is limited primarily by the ionospheric and tropospheric propagation errors in a single measurement.

Errors due to the ionosphere decrease as f^{-2} at VHF frequencies and above and thus may be reduced to an acceptable degree by the utilization of higher frequencies. Propagation errors due to the troposphere are essentially independent of frequency in the bands of interest but become the dominant source of error at C-band frequencies and above. Although the desired accuracy of a single fix suggests the use of high frequencies, the requirement to achieve better than a minimum signal-to-noise ratio invokes a minimum requirement on transmitter ERP and receiving antenna cross-section. Since the former is essentially limited by spacecraft technology and the latter implies receiving antenna directivity at the higher frequencies, a compromise is required between the achievable system accuracy and receiving system

complexity. The employment of satellite techniques for navigation of terrestrial transportation vehicles (aircraft, ships and military units) seems, on the surface, to be a relatively simple application of the system concepts and techniques already proven in space vehicle radio guidance, and, with respect to accuracy only, such is the case. The navigation requirements of terrestrial vehicles impose other requirements in addition to accuracy upon the output of a radio location system. The first of these requirements is the need for timely data. For high velocity vehicles, position and velocity data must be immediately available, and not require minutes or hours of computer smoothing to achieve the required accuracy.

The second requirement is that computations should be performed on board and not require the services of a central computer for readout of position and velocity. The final requirement is that the small user (general aviation, and the foot soldier) also require the services of an improved navigation system. The needs of such small users are not met with the complex and expensive terminals implied by present systems.

In Navigation Satellite systems operation, the precision with which satellite orbit determination and navigation by the user can be accomplished depends on many factors. The primary source of navigation signal errors arises in signal processing and propagation. Other important factors are errors in orbit determination resulting from uncertainties in tracking and knowledge of the Earth's gravitational field, system timing errors due to oscillator (clock) drifts in satellites and ground stations, and geodetic uncertainties introducing errors in location with respect to surveyed points on the Earth's surface. Additional errors may result if simplified estimation procedures are used.

The program will use receiving aircraft and ships as terrestrial users, automated spacecraft in conjunction with manned spacecraft, and a ground station network. Each test in the experimental program will be designed to verify a certain portion of the system range error model. Orbiting vehicles will be equipped with receivers and transmitters, connected as a transponder and antennas for reception and transmission. A ground station may serve as the master station or one of the orbiting vehicles may be the master station. The master station will require a master clock, signal generation equipment, a modulator and additional transmission equipment at the "uplink" frequency. All data is processed on the ground. A voice-order wire net may be employed for operational coordination. Figure 1-10 is a block diagram of the spacecraft navigation transmitter.

Equatorial synchronous-orbit and/or low-orbit spacecraft in the western hemisphere will be used, providing a variety of elevation angles to sites within the continental United States. Some of the essential spacecraft equipment for this experiment will include VHF and L-band transponders, a precision oscillator, and a range code

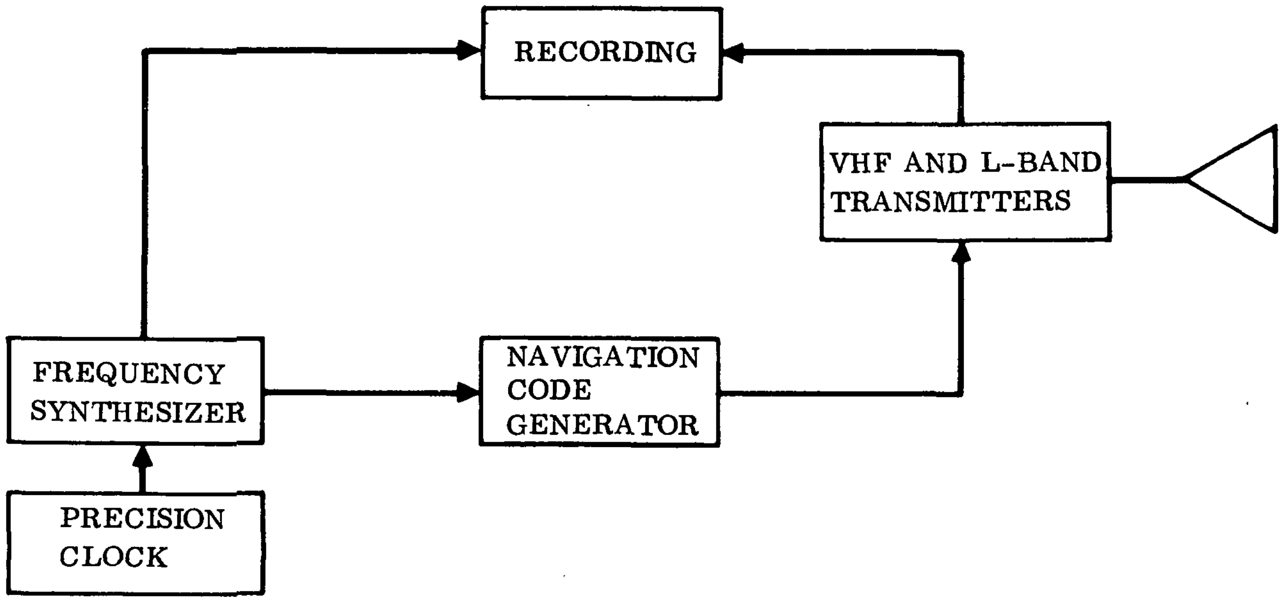


Figure 1-10. Spacecraft Navigation Transmitter

generator. This type of design will permit relay of the ground station and aircraft transmissions as well as transmission of satellite-generated range code signals.

1.4.4.3 Observation/Measurement Program. Parameters to be examined include: (a) the choice of operating frequency, (b) the accuracy of a single observation of range, or range difference, and/or velocity, (c) the accuracy and hardware implications of modulation techniques, (d) mechanization of matched filters and/or other means of reducing user terminal costs, (e) the employment of adaptive modulation techniques so that inherent accuracy is determined by user complexity and processing, and (f) propagation error statistics on various choices of system parameters. For a practical test program it may not be possible to fully simulate all aspects of system geometry; hence, emphasis should be placed on system modeling and the provision of statistical inputs to the error models.

Applicable theory is largely concerned with system representation and analysis. Due to the large number of contributing variables, not all of which are observable from the ground, no comprehensive theory of propagation phenomena is available. In general, it is necessary to synthesize new system concepts and measure error contributions. Usually one source of error is dominant, and as a result the law of large numbers does not apply; i.e., statistics are non-gaussian. Applicable areas in which a body of theoretical knowledge exists and in which data will be taken include tropospheric propagation, ionospheric propagation, multipath, search and acquisition, detection theory, theory of matched filters, and modulation theory. Relative signal levels will depend primarily upon the detection technique employed and must be adjusted to meet the requirements of the system being simulated. Variations of 30 dB in signal level are anticipated with system thresholds in the neighborhood of -90 dBm and lower.

1.4.4.4 Interface, Support and Performance Requirements. For many of the propagation effects to be considered, it is immaterial whether the transmitter is on the ground and the receiver in the satellite (thus minimizing data processing equipment), or the transmitter is on the satellite and the receiver in a ground station or mobile terminal (thus simulating operation geometry). However, to gain a true simulation of the signal multipath environment, it is imperative that the transmitter be in the satellite and that operational antennas be employed on the mobile terminal. The major portion of the propagation effects to be measured occur in the lower portion of the ionosphere and in the lower 6100m (20,000 ft) of the troposphere, hence the error models do not require an operational satellite (synchronous altitude orbit).

Consideration of the interferometer technique will require studying the spacecraft antenna baseline, antenna beamwidth, and angular resolution at the ground. The absolute accuracy will, of course, depend upon the satellite altitude. Baselines longer than are possible on one satellite can make for higher position-location resolution at the very considerable expense of coordinating two spacecraft, knowing their precise pointing and location at the time of measurement, and added computations.

To adequately model the satellite-constellation geometry two or more satellites are required; these may be combinations of the Space Station and one or more subsatellites or one or more synchronous altitude satellites. Particularly when it is desired to vary the radiated frequency parameter it may be most advantageous to employ reconfigurable space transmitters, such as the Space Stations and subsatellites.

1.4.4.5 Potential Role of Man. Man's in-orbit participation in the actual tests is minimal, since most data processing or recording is done at the user terminal. This suggests the desirability of tradeoff studies to determine the most cost-effective mix of automated and manned satellites. Equipment operation could easily be automated, and this experiment may well lend itself to performance by automated subsatellites. The desirability of varying many of the parameters for measurement recommends this experiment for performance by, or in conjunction with, the Manned Space Laboratory. Independent of the selected geometry, man's in-orbit participation will consist of:

a. Configuring the equipment for each test involving the Space Station.

b. Configuring subsatellites involved in each test.

c. Calibration of antennas and transmitter power.

d. Deployment and control of subsatellites.

e. Monitoring nominal operation of transmitters.

f. Turning on equipment.

g. Securing the space component after the tests.

1.4.4.6 Available Background Data. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TRW Systems (subcontractor).

1.4.5 ON-BOARD LASER RANGING

1.4.5.1 Experiment Objectives. The objectives of this experiment are to evaluate the utility of on-board laser ranging for spacecraft-to-spacecraft ranging as well as for altimetry.

1.4.5.2 Experiment Description. This experiment requires laser equipments with spectral radiant power output, modulation capability, and associated optical systems for transmitting and receiving for both space target ranging and altitude determination. The requirements are not entirely consistent. Both, however, should probably employ pulsed radar approaches. For the space target portion of the experiment, the radar performance should be evaluated against a cooperative target (augmented passive reflectors) at increasing ranges. In a later phase the range performance should be evaluated for uncooperative targets. Initial acquisition of the target in angle and in range should be a part of all range performance evaluations.

The target acquisition and pointing problems cannot at this time be definitized. Options available are the use of a passive infrared search device to provide target angular coordinates and acquisition information. Another option is the use of a very high power pulse-mode laser (probably a separate laser) to assist in target acquisition.

For the altimetry application, the choice of laser wavelength is a more critical parameter than in the space target case. The absorption and scattering properties of the Earth's atmosphere as well as the reflectivity of terrestrial features are critical to the choice.

The detection aspects of both potential laser applications are fairly similar. This is true so long as only direct (energy) detection and not heterodyne detection is employed. Based upon present knowledge of the relative difficulties, direct detection appears to be a good approach because of the unlikely use of lasers whose wavelengths are in the 10 μm region.

Signal processing and display equipment will also be required. The processing might be efficiently addressed through use of an on-board computer. The great flexibility thus obtained is desirable because of the many uncertainties in this experiment. Figure 1-11 is a block diagram showing a generic laser transmitter and a direct detection receiver.

1.4.5.3 Observation/Measurement Program. The observations to provide the required evaluation data are the usual measures of radar performance; e.g., detection probability, false-alarm probability, range and angle precision, and reliability. The program of measurements for the space target case should encompass both cooperative and uncooperative targets. In the latter case it would be desirable to investigate

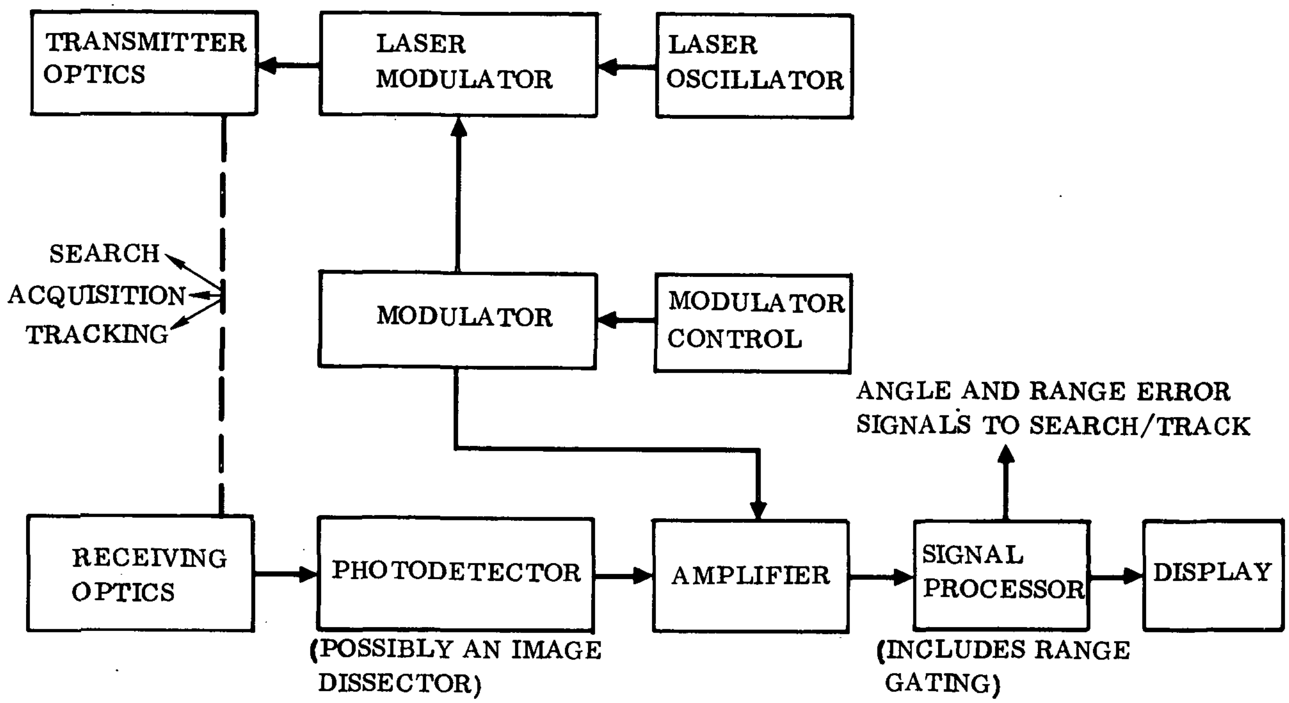


Figure 1-11. Laser Radar

the effects of a likely range of surface colors and characteristics. Since it is likely that a laser operating in the visible or near visible region will be used, this may not be essential; laboratory data may be applicable. Ranges from zero to about 555 km (300 n.mi.) should be covered.

An important experimental parameter in both the space target case and the altimetry application is the effect of background radiation. In the former case, the orbital parameters of both vehicles will determine the features of solar (and lunar) illumination. In the latter case, scattered radiation from the Earth and its atmosphere will in many cases illuminate the aperture of the laser radar receiver. In such cases, heterodyne detection offers highly selective filtering against such interference provided an acceptable wavelength could be chosen.

Measurements should be made for various background illumination conditions. It would be very interesting, particularly in the altimeter experiments, to study the return from cloud tops. Further, because the linear diameter of the laser beam at the Earth's surface will be about 61m (200 ft), there will be a certain amount of pulse smearing in the return. This "smear" contains information concerning the associated roughness (slope) distribution within the beam diameter. The measurements should include various conditions of cloud cover, weather patterns, climates, and geography (snow, desert, mountains).

Individual measurements should occupy only milliseconds or less, but should extend for sufficient time to maximize the utility and generality of the results. About one calendar year would be reasonable.

Data should be obtained to enable evaluation of the "effective thickness" of the atmosphere for laser wavelengths (time delay). It is assumed that frequencies can be chosen where dispersion (frequency-dependent time delay) will not be significant.

1.4.5.4 Interface, Support and Performance Requirements. This experiment has no real-time data transmission requirement. The results would be recorded and transmitted at low rates when link capacity allowed.

The potential eye damage interface posed by this experiment requires additional evaluation. This is especially the case for the space target situation. Protective glasses (narrow-band rejection filters) should be furnished to all crew members who might be in positions where the beam could be observed directly or by reflection. This includes members engaged in EVA.

The generation of EMI by the laser modulator requires attention as a part of the general EMI problem.

Consideration of the optical elements of the laser radar system include reliability under possibly large peak powers in the space environment, and the tradeoff concerned with placement of the transmitter and receiver front-ends inside or outside the spacecraft. The thermal control and solar radiation shielding are additional inputs to this tradeoff.

Attitude control required will depend upon the autotrack capability of the laser radar. This in turn depends upon the signal-to-noise ratio, and so will depend upon the system parameters and upon the tracker-to-target range. Attitude control for the altimeter experiments is less critical, but does not depend upon the angular scattering response of the illuminated area (Lambertian, or highly directional).

1.4.5.5 Potential Role of Man. Because of the relatively unknown behavior of laser equipment in spacecraft, the potential role of man in this experiment may be important. At short ranges, for the space target portion of the efforts, manual aiming would be employed. This is especially the case when rendezvous and docking experiments are underway. In the altimetry experiments, crew members could examine the altitude profiles generated and relate them (map-matching) to known topographical data.

In addition to these tasks, maintenance and reconfiguration work on both the laser subsystem and associated electronics would be required.

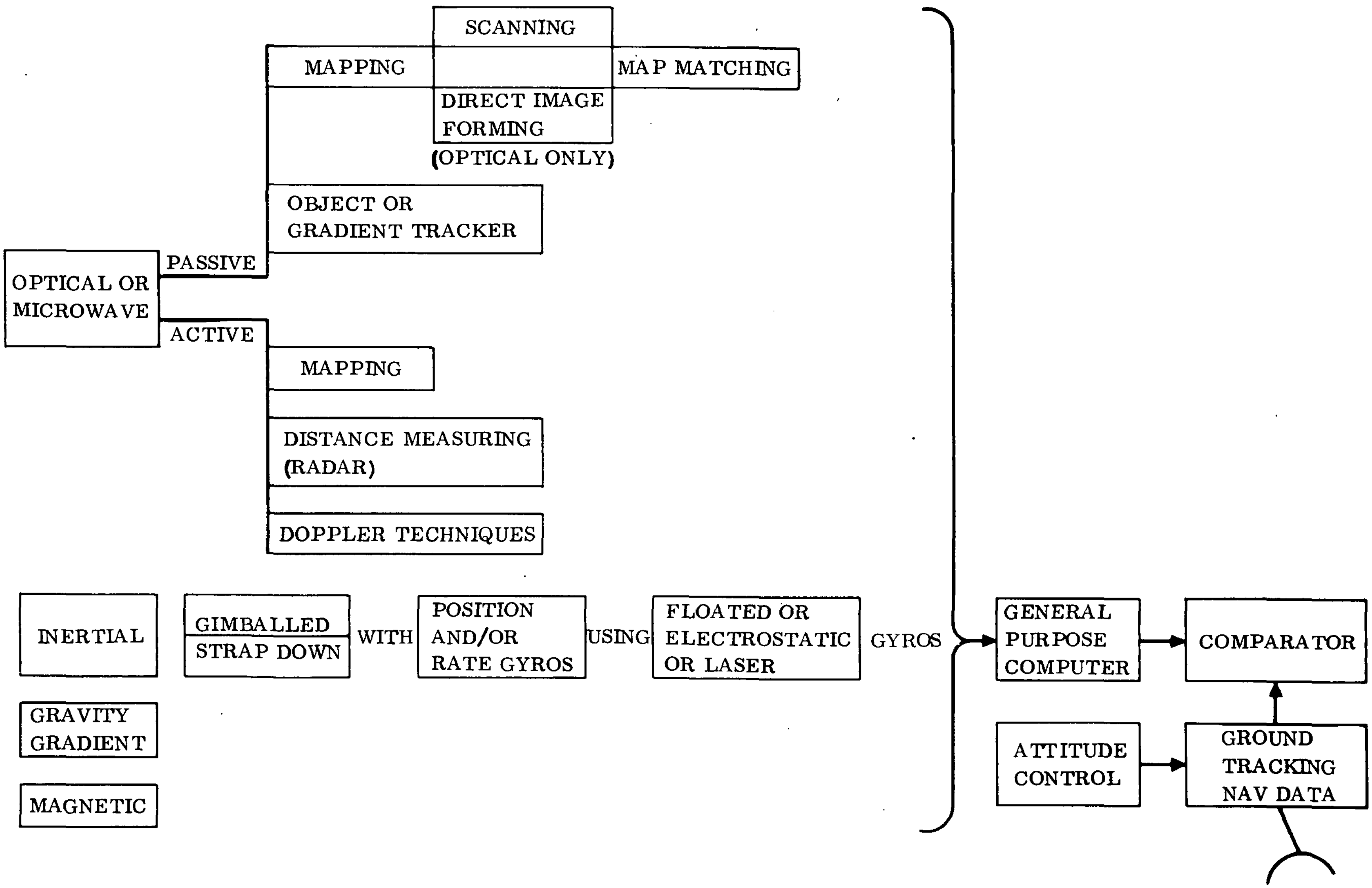


Figure 1-12. Sensor Systems

1.4.5.6 Available Background Data. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TRW Systems (subcontractor).

1.4.6 AUTONOMOUS NAVIGATION SYSTEMS FOR SPACE

1.4.6.1 Experiment Objectives. The objectives of this experiment are to provide a realistic evaluation for techniques, components, and systems useful in providing spacecraft with self-contained navigational ability. As used here, the term navigation encompasses the functions of vector position and attitude determination and their associated time rates of change.

1.4.6.2 Experiment Description. To meet the objectives the facility will have to provide support for a wide variety of potential navigation sensors. Both electromagnetic and inertial (stored reference direction or rate) categories will have to be serviced. Within the former category the range from optical (ultraviolet) through VHF are included. It is conceivable that magnetostatic devices might find some application.

The electromagnetic sensors can further be distinguished into radiating (active) and nonradiating (passive) techniques. The former are exemplified by "radar" (laser or microwave, including doppler) approaches and the latter by celestial object (stars, planets, or possibly man-made satellites) trackers. Also in the latter category are map matching or other topography-referenced approaches such as microwave mapping radiometers or television techniques. See Figure 1-12.

A fundamental complement to all conceivable approaches is a general purpose computer which can be programmed to furnish the required navigational data from the range of inputs available from possible navigational sensors. These inputs could be times, ranges or angles (or both) with respect to several possible coordinate origins.

The experiments would vary in specific content with the particular component or system being evaluated. However, they would generally be accomplished through setting up the particular sensors, programming the computer, and comparing the navigation signals thus obtained with, for example, the ground-system-based values.

1.4.6.3 Observation/Measurement Program. The observables in this experiment will be the set corresponding to the particular sensor(s) being evaluated. Generally, the measurements will be time intervals and/or angles (direction of arrival). These observables may be made with respect to an internal reference. In the case of active pulse radar, the range is proportional to the time between transmitted pulse and received echo.

The measurement would be performed at intervals and for durations consistent with providing error-performance data and bounds on mission profiles within which the particular technique would be useful.

1.4.6.4 Interface, Support and Performance Requirements. This experiment has no real-time data transmission requirement. Navigation data from ground tracking stations would be sent up to the spacecraft for evaluation purposes. Comparison would be performed on-board and the results transmitted later through the normal telemetry link.

There may be a possibility of temperature control for some type of sensor. Since the sensors are not yet defined, this is not yet considered an environmental support requirement.

Orbital parameters must be chosen to properly exercise the particular sensing technique. Orbits should include Earth orbits, translunar, rendezvous, and possibly interplanetary.

1.4.6.5 Potential Role of Man. Manned participation is essential for efficient performance of this experiment. It seems reasonable to evaluate more than a single technique on a given mission since a number of candidate sensors do not represent substantial power/weight/volume burdens. Man's job would be to perform the setup, including the appropriate software, and help evaluate the results of the comparison to the particular ground navigation-reference system.

1.4.6.6 Available Background Data. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TRW Systems (subcontractor).

1.4.7 TRANSMITTER BREAKDOWN TESTS

1.4.7.1 Experiment Objectives. The objectives of this experiment are to determine the limitations on transmitter system design due to voltage-induced breakdown.

1.4.7.2 Experiment Description. This experiment has its basis in several of the unique features of the space environment. To accomplish it requires a source of radiation capable of delivering up to 10 kW of power. The experiment consists of supplying a range of levels of microwave energy to several types of microwave structures. An example of such a structure is an antenna feed. In this case the feed and its associated antenna would be outside the spacecraft. The test feed could be instrumented so that precursor phenomenology could be observed. In addition, both forward transmitted (toward the antenna) and back (toward the oscillator) reflected power would be monitored. Excitation of atomic and molecular species contained

within the volume where breakdown might occur will narrowly precede ionization. Since this excitation will produce visible (or near visible) radiation, optical monitoring instrumentation should be provided in the test section.

Breakdown at microwave frequencies is a function of total pressure, concentration of "impurities," and the geometry of the microwave structure. See Figure 1-13. For this reason, instrumentation should be provided to monitor pressure (for example, a thermocouple gage) and a mass scanning spectrometer (mounted externally) to provide the time history of the concentration of the species within the test section prior to and throughout the breakdown interval.

The transmitter should be capable of producing a variety of different waveforms of different durations. For a given test structure – for example, the antenna feed mentioned earlier – no important differences would be expected for variations of microwave frequency within the bandwidth supportable by the given structure. It is not too likely that great differences would be observed, even for variations in frequency as great as 2:1. This of course would not be the case for some kinds of test section geometries, such as geometries in which large amplitude standing waves would be produced.

1.4.7.3 Observation/Measurement Program. The quantities desired from this experiment are the power levels which can be handled by radiating structures used in Comm/Nav systems. These results depend upon the frequency used and the pressure and constituents in and the geometry of the region where the high microwave power

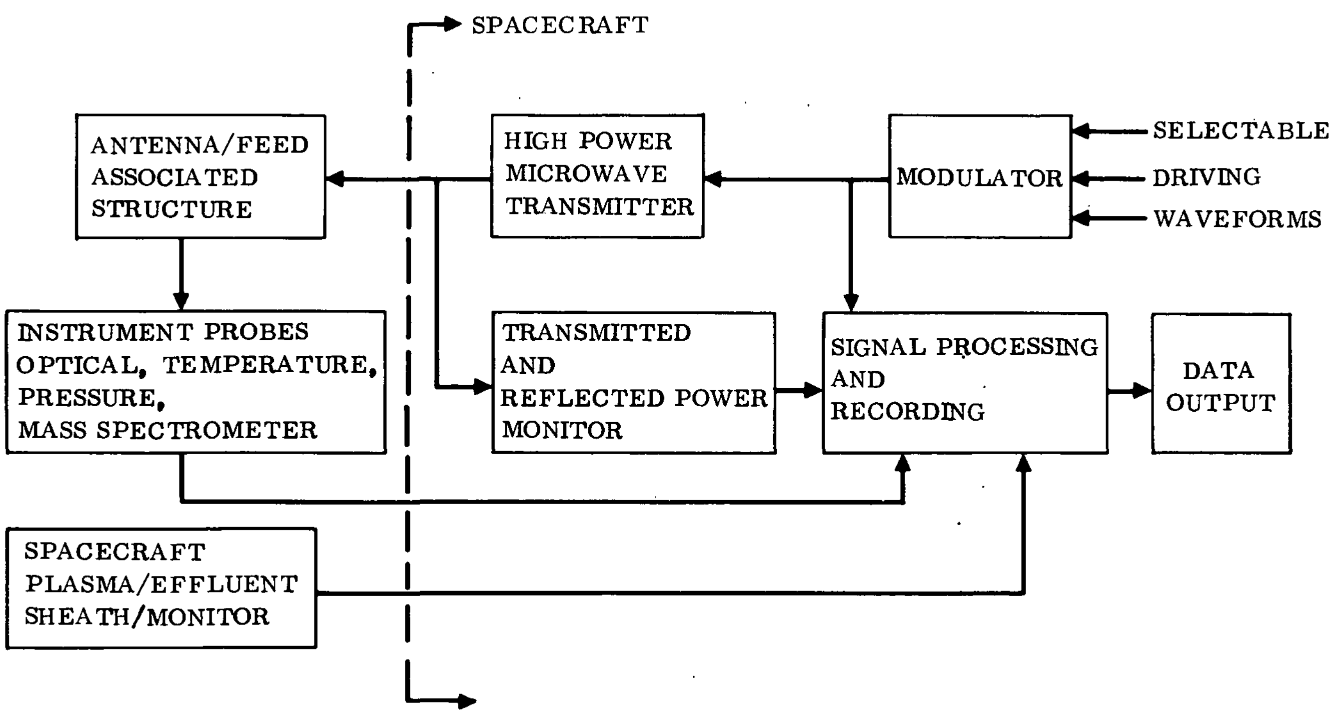


Figure 1-13. Transmitter for Breakdown Test

is applied. The pressure dependence means that there will be an altitude and time dependence. The latter will be affected not only by the local environment but also by the possible outgassing of the hardware itself.

Experiments on a given structure performed at S-band and possibly K-band should provide sufficient bounds so that correlations can be made with laboratory data and theoretical work.

Measurements should be made in all regimes of flight, possibly including boost. Those orbits and times in which the space-plasma density properties are fairly well known should be used for these breakdown measurements.

1.4.7.4 Interface, Support and Performance Requirements. This experiment has a number of interfaces. The first variety is that of perturbations from gaseous effluents from the spacecraft. If these effects are unavoidable and are deterministic, then the measurement should consider this. There will be considerable EMI generated by the large powers generated during the short intervals of the tests. The experiments could be performed on the experiment module, Station, or Shuttle. This experiment has no real-time data transmission requirements.

A possible experimental difficulty is that of permanent changes in the test structure resulting from the breakdown phenomena. Such changes include erosion of waveguide walls by sputtering, for example.

1.4.7.5 Potential Role of Man. There is a good chance that this will require physical examination of the experiment system several times during the measurements. This task requires crew member participation. EVA will be required, possibly after each test, until knowledge that the test conditions are known is reliable. It is likely that microscopic examination of the inner walls of the microwave test sections used will be required, and crew member participation will be further required.

1.4.7.6 Available Background Data. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TRW Systems (subcontractor).

1.4.8 TERRESTRIAL NOISE MEASUREMENTS

1.4.8.1 Experiment Objective. The objective of this experiment is to obtain the statistical bounds on levels of noise resulting from thermal emission and from other incoherent sources (not electronic oscillators) at Earth-oriented, spacecraft-borne receiving antennas.

1.4.8.2 Experiment Description. This experiment can be described in terms of mapping the Earth with wide-bandwidth radiometric-type receivers. A radiometric

receiver is defined as an antenna-receiver combination which produces an output signal proportional to the temperature of the material or objects within the antenna pattern. For electromagnetic waves in the 0.1 GHz to 100 GHz region, the power received from such a source which fills the angular subtense of the antenna beam can be written: $P = kT\Delta f$. If the system perceives a change in the power received, this can be interpreted as a change in the source temperature according to: $\Delta T = \Delta P/k\Delta f$.

The predetection bandwidth Δf is a fixed quantity characterizing the receiving system. The receiver may employ heterodyning or video detection. Preselectors may be used with either. As can be seen, the resolvable temperature difference between antenna spatial resolution elements, or between a spatial resolution element and a reference internal to the receiver, is inversely proportional to the predetection bandwidth. (For a Dicke-type radiometer the dependence is as $1/\sqrt{\Delta f}$.) The equipment alternatives are shown in the block diagram of Figure 1-14.

Equipment required therefore consists of antennas and receivers operating in the regions of the Comm/Nav Satellite frequencies. The data consists of a signal which represents the antenna temperature of the instantaneous resolution element, averaged over the antenna beam's footprint within the receiver bandwidth. This data must be recorded and related directly to the pointing angle and geographical location so that contours of given levels of noise power can be constructed.

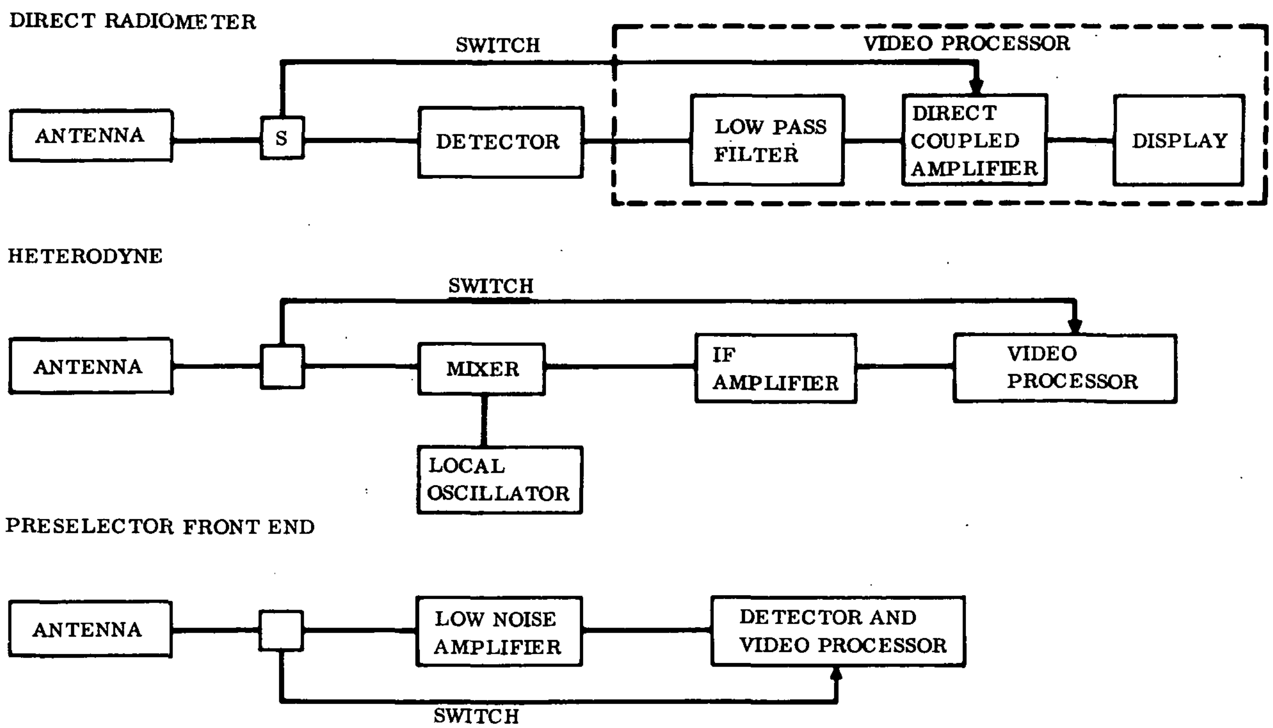


Figure 1-14. Noise Temperature Receivers

In some frequency regions there will be contributions to the antenna temperature which are contributed through the secondary lobes of the antennas. These contributions are those resulting from emission from solar, lunar, and galactic sources. The latter category includes the radiation due to interstellar atomic hydrogen at 1420 MHz. This suggests that some experiments be performed with an antenna in the opposite direction from that viewing the Earth so that perhaps these contributions can be distinguished.

A large-diameter space erectable antenna with changeable broad-band feeds would be a useful adjunct to this experiment.

1.4.8.3 Observation/Measurement Program. The basic observable is antenna temperature. For noise sources at thermal equilibrium, several special cases must be distinguished. For the Earth's solid surface, the polarization of the emitted and reflected radiation will vary with viewing angle. Water surfaces will also exhibit this effect but, in addition, behave more strongly as reflectors than emitters in the 0.1 GHz to 100 GHz region. The Earth's atmospheric emission will depend also upon the thickness encompassed within the antenna beam and strongly upon the frequency. Weather patterns will affect these noise measurements.

The frequencies used should be those ranges corresponding to present and forseen Comm/Nav system usage:

136 MHz - 150 MHz

300 MHz

1700 MHz - 1800 MHz

2250 MHz - 2300 MHz

3700 MHz - 4200 MHz

5925 MHz - 8400 MHz

16 GHz

32 GHz

Bandwidths of about 100 MHz should be employed in the 1 GHz and higher frequency region. Such values can provide ΔT resolution of $\sim 1°K$ within a considerable range of orbit and other system parameters.

Noise measurements should be made at about three-hour intervals, at least over locations which are likely to be covered by Comm/Nav satellite systems. Such measurements extending at least over a calendar year would be desirable.

1.4.8.4 Interface, Support and Performance Requirements. This experiment has no real-time data transmission requirement. Since a substantial amount of data will be collected on each pass, it seems reasonable to transmit it to Earth terminals so that the final results can begin to be useful, and also so that changes, as may be required, in the experimental program can be determined and executed.

1.4.8.5 Potential Role of Man. The role of man in this experiment will consist of configuring the spacecraft receivers and monitoring the data outputs. As the experiment proceeds it may be necessary to make certain changes; for example, post-detection integration time constants, and temperature of radiometer calibration source. The use of a large, space-erectable antenna would require EVA and special training.

1.4.8.6 Available Background Data

a. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TWR Systems (subcontractor).

b. B. R. Bean and E. J. Dutton, Radio Meteorology, National Bureau of Standards Monograph No. 92, March 1960.

1.4.9 NOISE SOURCE IDENTIFICATION

1.4.9.1 Experiment Objectives. The objectives of this experiment are to locate and identify sources of radiation in the 100 MHz to 100 GHz range due to electronic oscillators and other noise sources which cannot be categorized by thermal equilibrium. Examples are automotive ignition noise, gas discharge devices, industrial radio frequency equipment, and high voltage transmission lines.

1.4.9.2 Experiment Description. This experiment is accomplished through the use of broad-bandwidth antennas and panoramic receivers (scanning heterodyne) used with signal processing equipment. The equipment is to collect and analyze the signal environment for the purpose of determining interfering levels and associated modulation structures.

An oversimplified viewpoint, useful in obtaining some of the equipment and usage requirements, is that which assumes that the following triple product has a value which is constant.

$$(S/N)\ (\Delta\Omega)\ (\tau) = \text{Constant}$$

The three quantities are: signal-to-noise ratio (S/N), antenna beamwidth ($\Delta\Omega$), and dwell time (τ) of the beam at a given position. The latter quantity depends upon the orbit parameters of the spacecraft. If the antenna beam is made very narrow, giving

great precision in emitter location, then the dwell time also decreases, thus making it necessary for the signal level of the emitter to be large. That is, under such circumstances "weak" emitters will be identified with uncertainty. To make this model slightly more realistic, the additional variable, carrier frequency, can be added. This is equivalent to dividing up the dwell time per spatial resolution element into intervals within which a frequency search must also be carried out. Other such variables can also be added. Equipment for identifying the classes of known transmitters (commercial and industrial broadcast stations, radars, and certain varieties of industrial equipment) should be straightforward. For the range encompassing S-to-X-band, there is a considerable amount of equipment developed for military missions. It can generally be categorized as spectrum analysis equipment.

Figure 1-15 shows some typical equipment configurations.

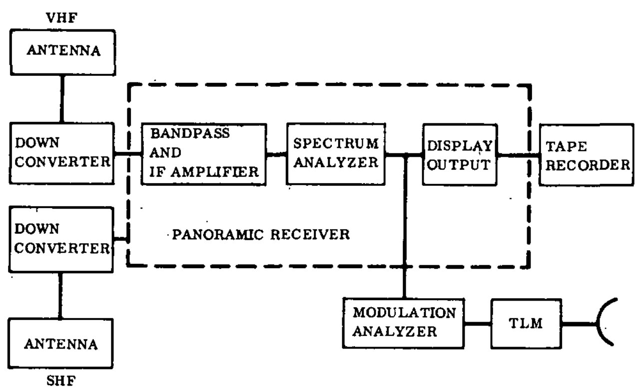


Figure 1-15. Panoramic Receiver

1.4.9.3 Observation/Measurement Program. This experiment will measure the power spectral density in selected frequency regions of Earth-based transmitters in selected geographical areas. The frequency regions to be covered are those corresponding to Comm/Nav satellite link assignments. Because potential sources of interference (Earth located sources) are not uniformly spatially distributed, the spacecraft receiver and processing equipment should provide for considerable adjustment of predetection bandwidth, frequency scan rate, and post-detection bandwidth. Predetection bandwidth should be selectable for at least two levels - for example, 100 kHz and 5 MHz.

The data on transmitters should include the geographical location and polarization of the transmitter. In some cases classification of the waveform (modulation format) would be desirable.

1.4.9.4 Interface, Support and Performance Requirements. The observations in this experiment could be perturbed by the presence of transmitting sources in nearby spacecraft. This problem would be eased by the use of directional antennas with very

low secondary lobes. However, it would be useful to determine the levels of tolerable interference due to other spacecraft transmitters.

Spacecraft orbit parameters are important because of the relative priorities for surveying various geographical areas. An experiment such as this could have substantial requirements for data link capacity. The link should be capable of supporting from 500 kbs to 1 Mbs.

1.4.9.5 Potential Role of Man. Crew participation is very important in this experiment. Selection of receiver bandwidth and frequency scan rates depending upon input signal density is important to the utility of the results. Monitoring of the data for anomalies is necessary since identification of some sources would be extremely difficult to mechanize. Even mechanized, its tolerance for small variations would render it of marginal utility.

1.4.9.6 Available Background Data

a. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TRW Systems (subcontractor).

b. Memorandum, S. W. Fordyce to R. W. Johnson (NASA Headquarters), A Radio Frequency Spectrum Analysis Experiment for the Manned Space Station Program, 7 May 1970.

c. Feasibility Study of Man-Made Radio Frequency Radiation Measurements from a 200-mile Orbit, Report No. GDC-ZZK68-007, Convair Division of General Dynamics, NASA Contract NASW 1437, 15 February 1968.

1.4.10 SUSCEPTIBILITY OF TERRESTRIAL SYSTEMS TO SATELLITE RADIATED ENERGY

1.4.10.1 Experiment Objectives. The primary objective is to identify and evaluate problems to communication systems on the Earth, due to possibly large flux densities produced by space-ground communication links. It is essential that practical quantitative bounds be established for allowable levels over the range of affected frequencies. Another portion of the experiment objective is to investigate the levels tolerable by the Space Station.

1.4.10.2 Experiment Description. The facility will provide for the production of a range of EIRP's within the various ranges of communication satellite frequencies:

136 - 150 MHz 300 MHz	Yagi or Logarithmic Array Antenna
1.700 - 1.800 GHz 2.250 - 2.300 GHz 3.700 - 4.200 GHz 5.925 - 8.400 GHz	Aperture Antenna
16 GHz 32 GHz	Optional

A portion of the system should be a large space-erectable aperture antenna with changeable feeds. With modest transmitter power a 6.1m to 9.15m (20 ft to 30 ft) antenna could produce large EIRP's on the Earth from a 500 km (270 n.mi.) spacecraft altitude.

Such a system has the additional great advantage that the footprint of the antenna would be small. This is important in this experiment since inadvertent interference with a communication link could be very serious. The beam would be positioned at agreed-upon locations, times, and durations.

Signals at varying EIRP's, frequencies, and polarizations should be used. Both narrowband and wideband waveforms should be employed to ensure maximum interaction with the various kinds of terrestrial links. See Figure 1-16.

1.4.10.3 Observation Measurement Program. A significant portion of this experiment is in arranging the locations and times when interference tests can be made. Once this is done an agreed-upon program sequence of power levels, frequencies, and signal structures is executed. Possibly several passes over the ground point would be required for each frequency.

1.4.10.4 Interface, Support and Performance Requirements. It is possible that the large EIRP levels generated will interfere with some of the spacecraft's own subsystems. This experiment calls for accurate antenna pointing, but normal spacecraft

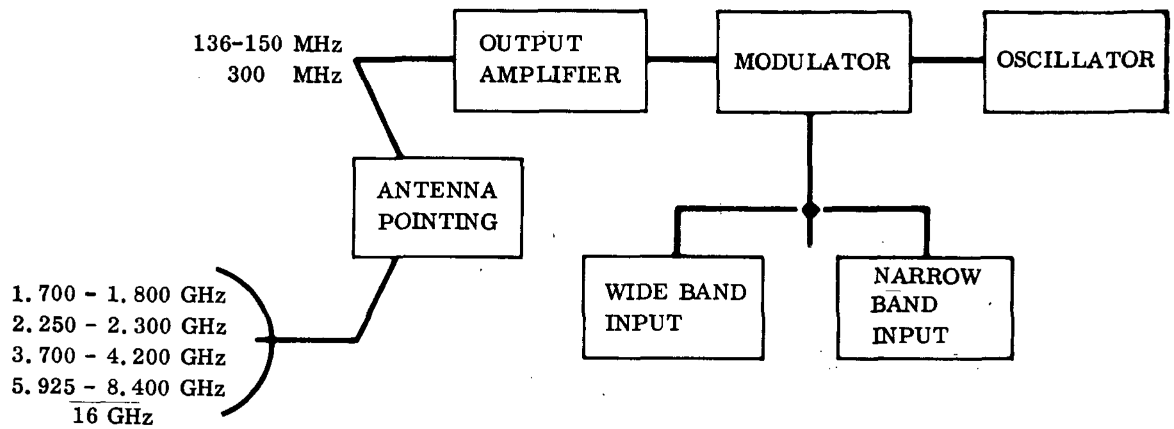


Figure 1-16. Terrestrial Link Susceptibility Experiment

attitude tolerances should be acceptable. If a 9.15m (30 ft) erectable antenna were employed at 30 GHz, a beam width of 8.72×10^{-4} rad (0.05 deg) would be produced. It is not likely that an erectable structure could be used to its diffraction-limited beamwidth at 30 GHz, however. The ideal beamwidth for such an antenna at 8 GHz would still be only about 2.62×10^{-3} rad (0.15 deg).

No real-time data transfer is required by this experiment except for a space-ground voice link to coordinate tests, and possibly make changes in the program sequence.

1.4.10.5 Potential Role of Man. The crew would have the responsibility of erecting the antenna, for which special skills might be needed. They would also be responsible for ensuring the immunity of all but the selected Earth location from irradiation.

1.4.10.6 Available Background Data. Memorandum, S. W. Fordyce to R. W. Johnson (NASA HQ.), A Radio Frequency Spectrum Analysis Experiment for the Manned Space Station Program, dated 7 May 1970.

1.4.11 TROPOSPHERIC PROPAGATION MEASUREMENTS

1.4.11.1 Experiment Objectives. The objective of this experiment is to collect and analyze propagation data for electromagnetic waves in the range 0.1 GHz to 30 GHz. (The range from 30 GHz to 300 GHz is covered in Millimeter Wave Propagation.) Before systems can be designed which call for use of these frequencies in the Earth's atmosphere, statistical data must be available; for example, on the percentage of the time when the attenuation in a given frequency range exceeds 10 dB, 20 dB or 30 dB. Such data must be known for a variety of locations, weather conditions, and satellite-ground terminal geometries. The data to be obtained and so analyzed includes both

attenuation and phase-modifying characteristics. The latter category encompasses time delay, frequency-dependent time delay, beam bending (refractive correction), and beamwidth broadening. In this frequency range, space diversity must also be considered since weather patterns responsible for degrading link quality may be geographically rather localized. It is thus important to know how far away a receiving terminal must be so that the localized weather can be avoided by the link.

1.4.11.2 Experiment Description. The experiment consists of configuring a sequence of spacecraft receivers corresponding to a set of programmed transmissions from each of various ground stations. A block diagram of the spacecraft equipment is shown in Figure 1-17. To provide the most useful data, the transmitting ground stations should be located so that the range of elevation angles from zenith to at least 8.72×10^{-2} rad (5 deg) can be included. The spacecraft receivers must provide for calibration of receiver noise level and dynamic range. In addition, signal processing and recording capability must be provided so that the crew can choose the best operations for each measurement circumstance.

The choice of a set of test frequencies is less critical in this range as compared to the millimeter wave range, since there is only a single molecular resonance absorption included. This is the resonance due to uncondensed water vapor at about 22 GHz. The frequencies shown on the block diagram of the spacecraft receivers represent choices encompassing the relative maximum of absorption at 22 GHz and also samples down to the lower bound of the range. At a frequency not far from this bound, at 100 MHz, some propagation effects due to the troposphere and ionosphere may be about equal in magnitude.

1.4.11.3 Observation/Measurement Program. The observables in the spacecraft are: received signal level, frequency, relative phase, and direction of arrival. These quantities will be required for the following set of conditions:

Ground terminal elevation angle	Zenith to $\leq 8.72 \times 10^{-2}$ rad (5 deg)
Clock time	Day and night
Calendar time	All seasons
Weather conditions at terminal	At least one year's sample
Terminal location	Arctic, temperate and tropical

Additional frequency-choice considerations are:

a. At 13 GHz-32 GHz greatest sensitivity to water vapor content occurs.

b. At >3 GHz effects of rain may be severe.

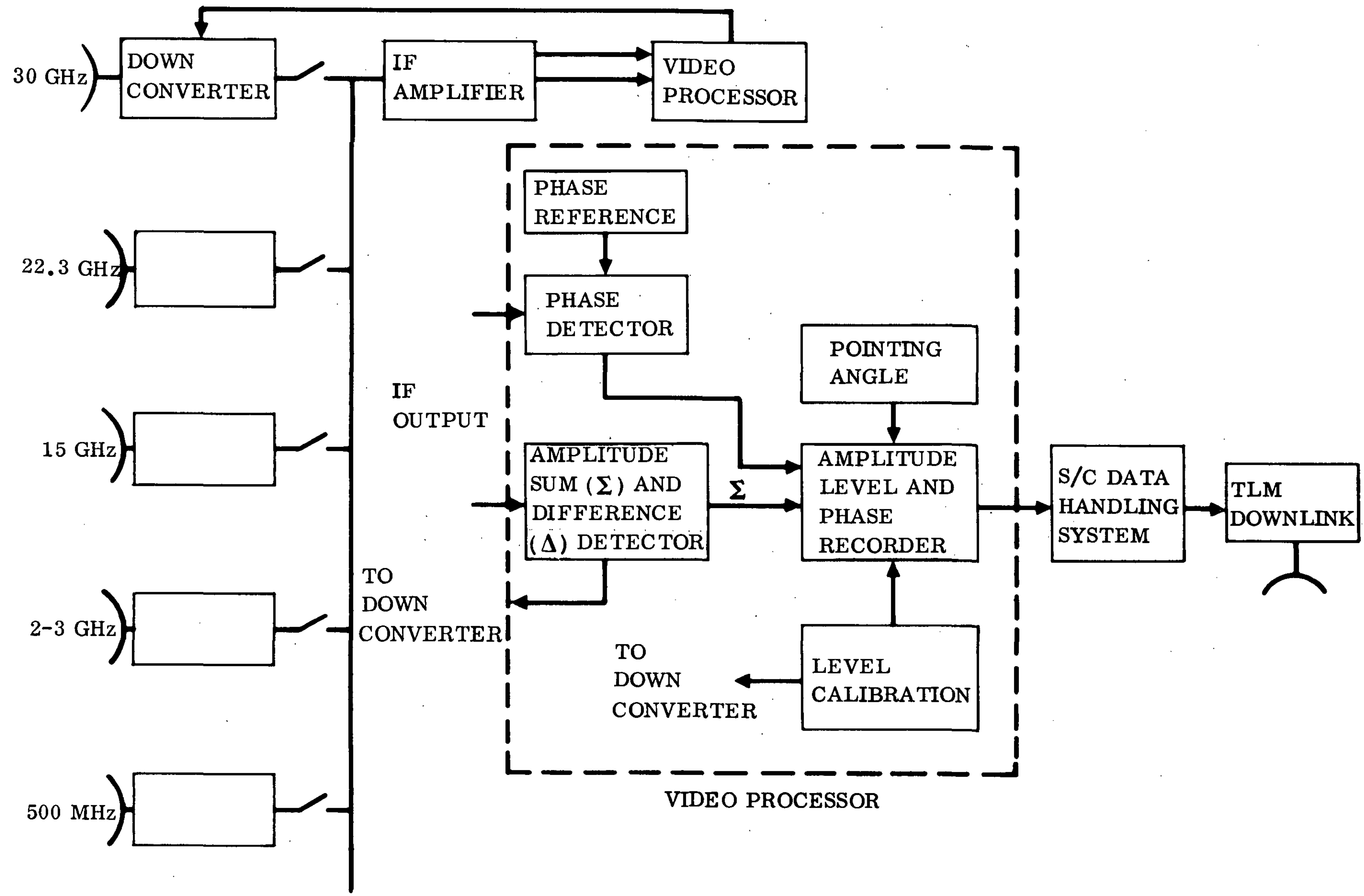


Figure 1-17. Tropospheric Wave Propagation — Space to Ground Measurements

c. At 100 MHz attenuation (precipitation and gaseous absorption) will exceed ~0.08 dB one percent of the time (averaged over continental U.S.).

Figure 1-18 is included for reference. An additional frequency choice consideration, namely the possibility of detection in these measurements of certain atmospheric pollutants, is shown in Table 1-5 which lists the microwave absorption for sulfur dioxide, nitrous oxide, nitrogen dioxide, and ozone.

On this basis it is reasonable to choose carrier frequencies typified by the following:

500 MHz

2-3 GHz

15 GHz

22.3 GHz (absorption peak)

30 GHz

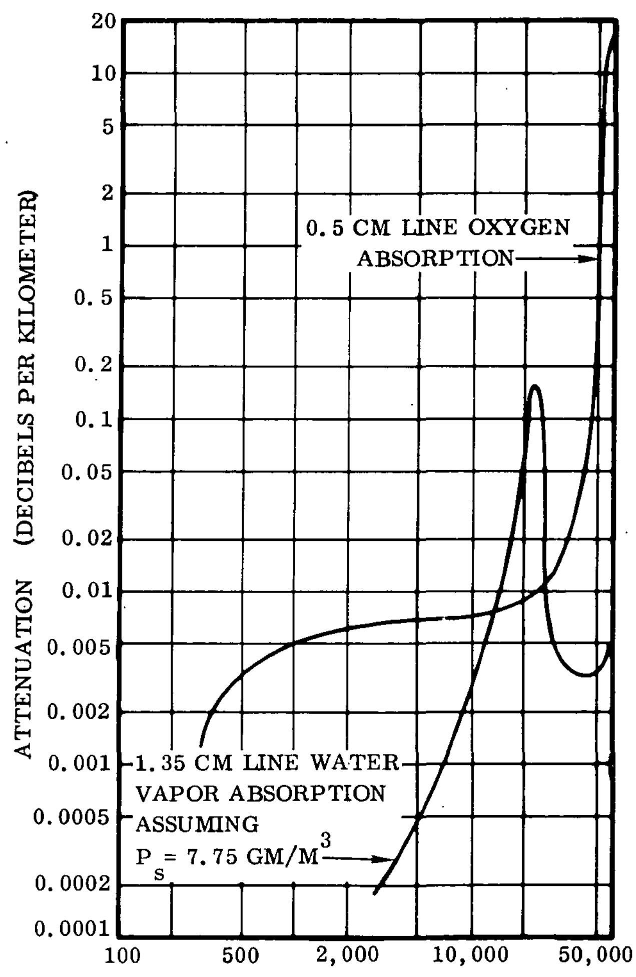


Figure 1-18. Atmospheric Absorption by the 1.35-cm Line of Water Vapor and the 0.5-cm Line of Oxygen

Table 1-5. Microwave Absorption Coefficient (γ) for Inorganic Air Pollutants

Gas	MHz	γ Max (dB/km)	Percent by Volume At Ground	γ At Ground (dB/km)
SO_2	12,258.17	1.9×10^{-1}	$(0 \text{ to } 1) \times 10^{-6}$	$(0-1.9) \times 10^{-7}$
	12,854.54	8.7×10^{-1}		$(0-8.7) \times 10^{-7}$
	23,433.42	1.2×10^{-1}		$(0-1.2) \times 10^{-7}$
	24,304.96	2.3		$(0-2.3) \times 10^{-6}$
	25,398.22	2.1		$(0-2.1) \times 10^{-6}$
	29,320.36	3.3		$(0-3.3) \times 10^{-6}$
	44,098.62	5.2		$(0-5.2) \times 10^{-6}$
	52,030.60	9.5×10^{-1}		$(0-9.5) \times 10^{-7}$
N_2O	24,274.78	2.5	0.5×10^{-6}	1.25×10^{-6}
	22,274.60	2.5		1.25×10^{-6}
	25,121.55	2.5		1.25×10^{-6}
	25,123.25	2.5		1.25×10^{-6}
NO_2	26,289.6	2.9	$(0 \text{ to } 2) \times 10^{-8}$	$(0 \text{ to } 5.8) \times 10^{-8}$
O_3	10,247.3	9.5×10^{-2}	Summer $(0 \text{ to } .07) \times 10^{-6}$	$(0 \text{ to } 6.3) \times 10^{-9}$
	11,075.9	9.1×10^{-2}	Winter $(0 \text{ to } .02) \times 10^{-6}$	$(0 \text{ to } 6.3) \times 10^{-9}$
	42,832.7	4.3×10^{-1}		$(0 \text{ to } 2.8) \times 10^{-8}$

These measurements can probably best be made using a synchronous satellite, although ground terminal location might be more difficult than if a lower altitude vehicle were employed. In addition, because of the range of frequencies, it would not be possible to form narrow beams without the use of a large space-erectable antenna such as that considered in Section 4.10 Terrestrial System Susceptibility.

1.4.11.4 Interface, Support and Performance Requirements. As in the other Earth atmospheric propagation experiments, the data rate requirements are modest: about 30 kbs. If a synchronous-altitude vehicle is considered, a doppler tracking local oscillator is probably not required. The use of a large space-erectable antenna would provide some problems of pointing and stabilization. If this antenna were to be used at frequencies as high as 30 GHz to produce narrow beams, special consideration would have to be given to control of nonuniform heating (and resulting expansion) of the antenna surface.

1.4.11.5 Potential Role of Man. It is likely that crew participation in antenna erection and aiming would be required. Additional tasks would be to set up the proper receiving and recording system according to the program established. Certain weather patterns observed might be taken advantage of if a ground terminal (possibly a ship) were in position.

1.4.11.6 Available Background Data

a. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TRW Systems (subcontractor).

b. B. R. Bean and E. J. Dutton, Radio Meteorology, National Bureau of Standards Monograph No. 92, March 1960.

1.4.12 PLASMA PROPAGATION MEASUREMENTS

1.4.12.1 Experiment Objective. This experiment has as its objective the collection of data in actual re-entry cases so that the practical bounds on the performance of communication links in such an environment can be determined. Without such data the large body of theoretical and laboratory-derived knowledge cannot reasonably be used to make link parameter and implementation decisions.

1.4.12.2 Experiment Description. This experiment can be described in terms of the monitoring of transmissions from a vehicle entering the Earth's atmosphere from a Space Station or from a subsatellite deployed from an experiment module. Because the general features of the frequency response of re-entry plasmas are known, it is possible to place some bounds on the choice of frequencies to be used. To carry out this experiment, tracking antennas and receivers in the spacecraft must be configured corresponding to the chosen set of transmitters in the re-entry vehicle. Within the re-entry vehicle certain quantities must also be measured and recorded. Principal among these are the complex VSWR during the re-entry, and vehicle attitude and altitude history. The latter quantity as well as velocity profile and meteorological conditions can be obtained from simultaneous ground observations. It is assumed that the geometry and composition of the re-entry probe are known. It might be useful for the probe to be furnished with a mass spectrometer to obtain an in situ measure of outgassing species which would contribute to the total plasma environment. The space

observation platform (Station or experiment module) will contain recorders and telemetry equipment for either real-time or delayed transmission to ground data readout terminals. The general configuration for these experiments consists of relatively broad beam (~0.175 rad; 10 deg) antennas on the re-entry probe, and probably narrower beam (3.49×10^{-2} to 8.72×10^{-2} rad; 2 to 5 deg) tracking antennas on the spaceborne platform. Measurements should, at least initially, be made for two orthogonally linearly polarized signals. Even these measurements of signal strength are extremely difficult to extract highly deterministic results from because of the uncertainties in the contributing variables. Depending upon the progress in obtaining statistically well-behaved results, it would be desirable to consider going beyond the monitoring of received-signal strength. For example, it would be very useful to obtain data in the list below.

a. Angular dependence of frequency response of re-entry plasma. Requires broad-beam antenna on probe permitting multiple observing platforms (RAM and subsatellite).

b. Angle of arrival changes due to diffraction of radiation by finite re-entry plasma boundaries.

c. Effect of dispersion (frequency dependence of phase velocity) on data rate. This can be due to two causes: the dispersion indicated in b above and the (probably smaller) dependence of plasma refractive index on frequency, and possibly on the value of magnetic field.

These are suggested on the basis of the "real-life" facts that re-entry plasmas change their physical parameters with time, and exhibit spatial bounds which are a function of the frequency used to probe them. Polarization effects (magnetically induced rotations) are generally negligible in the microwave range, but can be significant if the path-length is sufficiently large. See Figure 1-19.

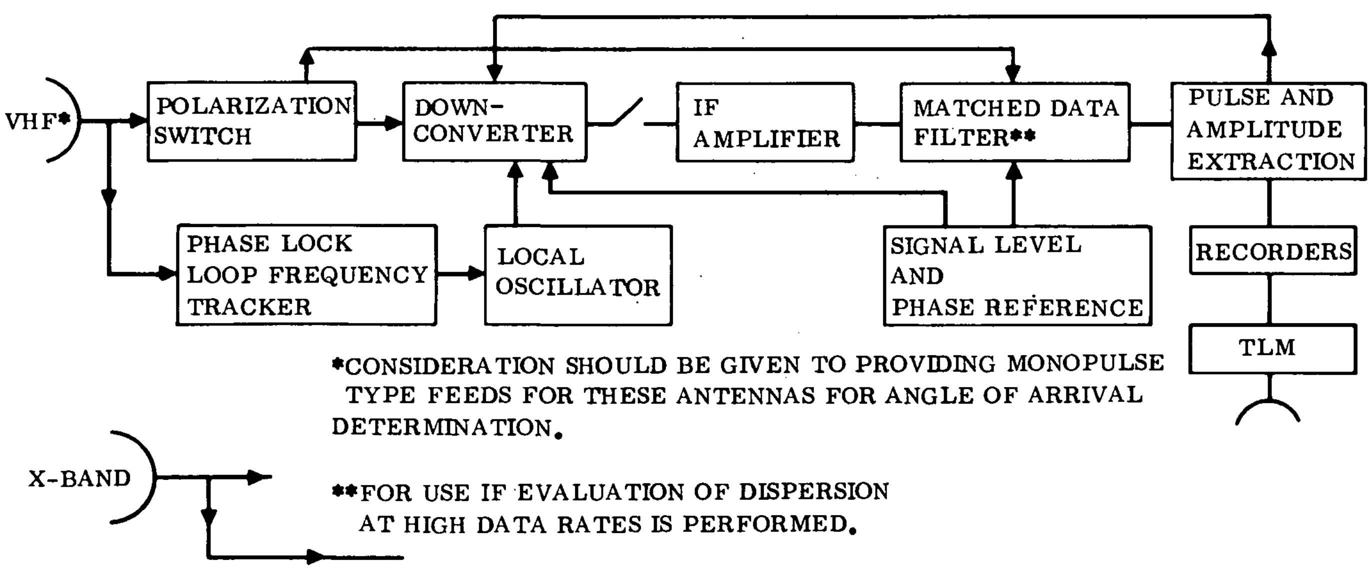


Figure 1-19. Plasma Propagation Equipment

These experiments would require more complex instrumentation in both the re-entry probe and in the monitoring station. The general requirements would be for transmission of sets of both analog and digital data streams from the probe, and comparison to replicas in the spaceborne receiving station(s) and also possibly at the ground. These replicas would be uncorrupted by the re-entry plasma.

Although not directly a portion of the considerations here, the problem of antennas that can survive the range of alternative re-entry conditions is an important one.

This plasma propagation experiment would be useful to evaluate the effects of physical and chemical means of modifying re-entry plasmas.

1.4.12.3 Observation/Measurement Program. The measurements are to be made on a cooperative probe entering the Earth's atmosphere. Re-entry angle as well as drag coefficient are important variables. The classes of experiments described in the previous section should be implemented at VHF and X-band, at least. The use of higher frequencies should be considered on the basis that the duration of a given level of attenuation (blackout) is generally a monotone decreasing function of the frequency. It is difficult to make a more quantitative statement because of the frequency-dependent effects of diffraction, refraction, antenna beamwidth, and possibly polarization.

The observables in this experiment will be (as a function of time) received-signal strength, at least at one spaceborne receiving terminal; angle of arrival, orientation, and polarization state of the received signal; and data rate supportable by the plasma environment. It might be possible in this experiment to assess the contribution to antenna noise of a re-entry plasma.

1.4.12.4 Interface, Support and Performance Requirements. The experiments described here have no real-time telemetry data requirements. Auto-track receiving antennas might be called for when frequencies of perhaps X-band and higher are employed. For most re-entry geometries it is likely that broadbeam antennas on both the probe and spacecraft receiving platform could be used. Because there is not a strong requirement for very narrow beam antennas, wide-bandwidth antenna response can be obtained, thus easing pointing requirements. Ephemeris control is important in this experiment since the re-entry trajectory must satisfy both viewing from the spaceborne platform and from a well-instrumented ground station. If two spaceborne receivers are employed (angular response experiment), then a data link between, for example, the Space Station and a remotely located subsatellite would be needed. This would not need to be a real-time link, although such a link might be more desirable than the inclusion of recorders in the subsatellite.

1.4.12.5 Potential Role of Man. Crew participation and support would include appropriate equipment connection and monitoring of some of the recorded outputs to assist

in timely diagnosis of the need for experiment and program modifications. Initial antenna pointing and alignment might be assisted by the crew.

1.4.12.6 Available Background Data. Plasma Physics and Magnetohydrodynamics in Space Exploration, NASA SP-25, Office of Scientific and Technical Information, December 1962.

1.4.13 MULTIPATH MEASUREMENTS

1.4.13.1 Experiment Objectives. The objectives of this experiment are to obtain the short-term (minutes, hours) statistical behavior of signals received via different propagation paths between terrestrial users and spacecraft, and between spacecraft.

1.4.13.2 Experiment Description. This experiment employs spacecraft antennas and transmitters in the VHF, L-band, and X-band regions. These transmitters are provided with modulators capable of supplying various modulation waveforms. Continuous wave signals having broad spectra are of special interest. The experiment consists of using the spacecraft transmitters to provide signals which are received at aircraft. Measurements will also be made at another spacecraft, both directly and via a relay satellite (TDRS).

A typical spacecraft transmitter is shown in the block diagram of Figure 1-20.

1.4.13.3 Observation/Measurement Program. The measurements will include both path-loss and fading characteristics. The latter includes fade depth and fade rates. These quantities will depend upon the frequency band used and the terrain. The

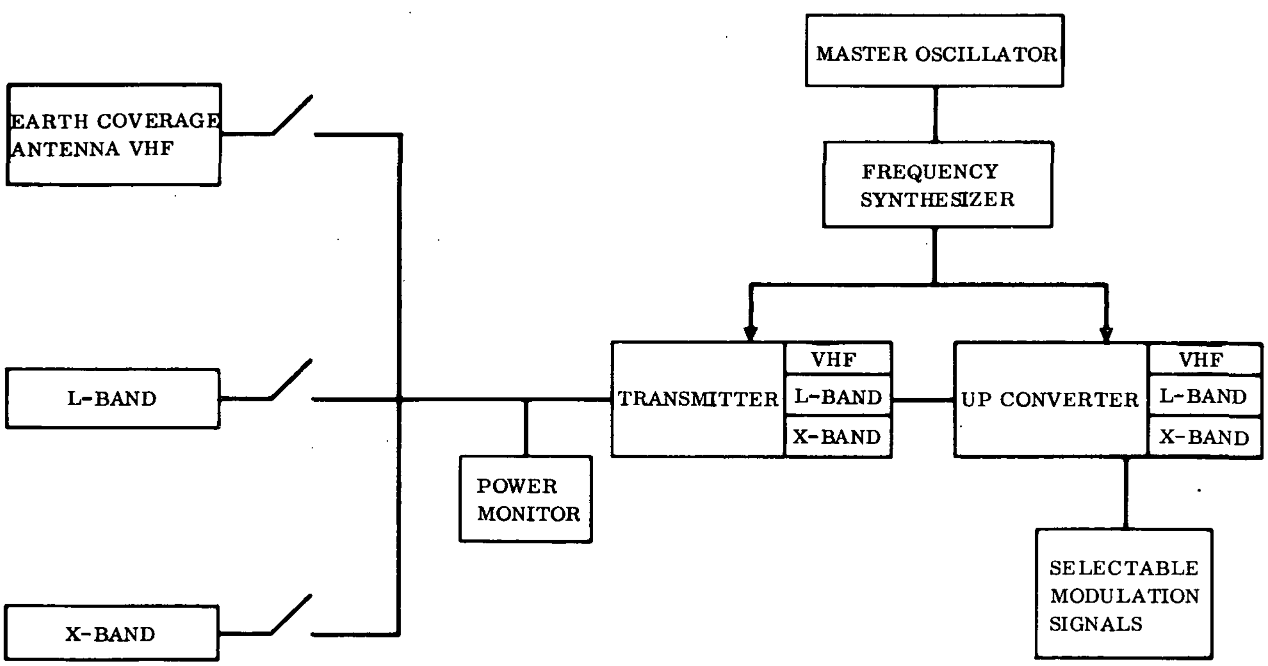


Figure 1-20. Multipath Measurements

character of the latter as regards its surface roughness and its conductivity are the variables of interest. Also important is to assess the combined effects of the multipath and the ionosphere. Such evaluation is particularly important at VHF and L-band. For multipath measurements involving aircraft, measurements should be made for different ranges of aircraft altitudes.

1.4.13.4 Interface, Support and Performance Requirements. This experiment may involve use of the Space Shuttle, Space Station, and possibly subsatellites as receiving stations. They may receive transmissions directly or via a TDRS. It is likely that in a complicated experiment such as this, some space-to-ground data link capacity would be used to relay data to experimenters there. This capacity would probably be about 3 kbs.

1.4.13.5 Potential Role of Man. The role of man in this experiment is to perform system checkout and testing as well as to set up and possibly steer antennas. When data is obtained, he will compare the results obtained on various paper of the same area and elect to repeat them depending upon the comparison.

1.4.13.6 Available Background Data. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TRW Systems (subcontractor).

1.5 INTERFACE, SUPPORT AND PERFORMANCE REQUIREMENTS

The functional program element (FPE) for Communications and Navigation is the Com/Nav Research Facility. To fulfill its function, this facility is to be a versatile laboratory providing a "core" of services and equipments required to support typical experiments as described in Section 1.4.

The summary data presented in Table 1-6 represents, in the best judgment of NASA scientists, the overall facility and experiment requirements to accomplish a realistic experimental program. The rationale for selection of the summary parameters is in some instances arbitrary but has as a basis the total NASA experience and knowledge of prior flight, experiment-definition, and integration programs.

The Com/Nav Research Facility has the capacity to support several experiments on a mission, thus taking advantage of similar orbital requirements and also minimizing equipment transfer logistics.

1.6 POTENTIAL MODE OF OPERATION

The Communications/Navigation Research Facility is envisioned as a manned laboratory in which the thirteen "typical" Communications/Navigation experiments may be conducted. A preliminary assessment has been made of these experiments to determine how the experiment objectives might be accomplished, considering

Table 1-6. Com/Nav Research Facility FPE Interface, Support and Performance Requirements

Mass	756 kg (1670 lb)
Volume	5.2 m^3 (184 ft^3)
Power (during data collection)	2.64 kW
Crew Skills	Electronics Engineer, Electromechanical Technician, Optical Technician, Microwave Specialist
Data Rate	1.04×10^6 bps
Logistics – up/30 days	28.6 kg (63 lb)
Logistics – down/30 days	28.6 kg (63 lb)
Pointing and Stability	Accuracy: 0.000175 rad (0.01°) Rate: 0.00175 rad (0.1°) per sec
Inclination	0.49 rad (28°) except Exp. 8 and 9; Experiments 8 and 9 require 0.95 rad (55°) minimum
Altitude	185 km (100 n.mi.) or greater
Environment	None except RFI compatibility

three possible manned modes of operation. These modes of operation are as follows:

a. Limited On-Orbit Stay-Time (up to 30 days) as With the Space Shuttle.

b. Extended On-Orbit Stay-Time Revisited Periodically by a Shuttle.

c. Extended On-Orbit Stay-Time for the Space Station.

The information presented in Table 1-7 is the result of this assessment. It is not the intent that this data should in any way restrict the accommodation of any of the experiments to a specific mode of operation.

1.7 ROLE OF MAN

With the advent of "man in space" a new dimension of freedom in configuration and performance of experiments in space has arrived. It is not the intent in this

Table 1-7. Potential Mode of Operation

Experiment		Mode of Operation*			Remarks
Number	Title	A	B	C	
1.4.1	Optical Frequency Demonstration	Yes_1	Yes_1	Yes_1	1. Estimate four one-month equivalent periods to cover four seasons of weather. Mode A, B or C acceptable; B or C preferred.
1.4.2	Millimeter Wave Communication & Propagation	Yes_1	Yes_1	Yes_1	2. Estimate a minimum of one month to evaluate a given space-Earth link. Mode A, B or C acceptable; B or C preferred.
1.4.3	Surveillance & Search & Rescue Sys. Demonstration	Yes_2	Yes_2	Yes_2	3. The total study of probability of detection, false alarm rate, acquisition and dependence upon target background contrast makes Mode B or C plus targets preferable; A is acceptable.
1.4.4	Satellite Navigation Techniques for Terrestrial Users	Yes_2	Yes_2	Yes_2	4. Results must be verified by ground tracking. With this constraint and several candidate sensor systems, Mode B or C is preferable; A acceptable.
1.4.5	Onboard Laser Ranging	Yes_3	Yes_3	Yes_3	5. The experiment may be run about one "breakdown" per orbit. A Mode A accommodation may even give the variation of altitude required for this experiment.
1.4.6	Autonomous Navigation Systems for Space	Yes_4	Yes_4	Yes_4	6. One complete map requires about a full year's measurement with an antenna BW of 1.745×10^{-2} rad (1 deg). Considering variation of coverage with altitude, Earth temperature, atmospheric

Table 1-7. Potential Mode of Operation (Cont)

Experiment		Mode of Operation*			Remarks
Number	Title	A	B	C	
					conditions and frequency, it is apparent this type of survey should cover several years. The data is immediately useful, becoming increasingly so as the measurement time is extended. Mode C is preferred.
1.4.7	Transmitter Break-down	Yes_5	Yes	Yes	7. This is a mapping task where complete coverage is less important than in the previous experiment. However, to map populated areas and several discrete radiators or complexes of radiators suggests a minimum of a calendar year. Mode C is preferred.
1.4.8	Terrestrial Nose Measurements	No	No	Yes_6	8. One set of susceptibility measurements with a pre-arranged ground station is estimated to require one month. Mode B or C preferable; A is acceptable.
1.4.9	Noise Source Identification	No	No	Yes_7	9. Measurement involves correlating field strength, phase, and angle of arrival with elevation angle and weather. Mode B or C preferable; A is acceptable.
1.4.10	Susceptibility of Terrestrial System to Satellite Radiated Energy	Yes_8	Yes_8	Yes_8	10. Simultaneous multiple space observing platforms and simultaneous VHF and X-band transmission-receiving links would permit accomplishing intent of FPE in approximately 10 entries. On a

Table 1-7. Potential Mode of Operation (Cont)

Experiment		Mode of Operation*			Remarks
Number	Title	A	B	C	
					single-link basis, 30 entries is more realistic. Mode B or C preferable; A is acceptable. It should be noted that Shuttle may, in some cases, serve as the re-entry body.
1.4.11	Tropospheric Propagation Measurements	Yes_9	Yes_9	Yes_9	11. A large quantity of data with prearranged stations whose geographical dispersion is limited indicates this experiment requires calendar time in excess of one month. Mode B or C is required.
1.4.12	Plasma Propagation Measurements	Yes_{10}	Yes_{10}	Yes_{10}	
1.4.13	Multipath Measurements	No	Yes_{11}	Yes_{11}	

*Mode of Operation
A. Limited on orbit stay-time (up to 30 days) as with Space Shuttle.
B. Extended on orbit stay-time revisited periodically by a Shuttle.
C. Extended on orbit stay-time for the Space Station.

paragraph to compare the cost of performing an experiment with automatic equipment in a small satellite against the cost of performing this experiment with man's assistance in a larger orbiting space laboratory. It is rather the intent to point out the freedom that exists with man "in the loop."

It is of paramount importance to note that man may observe data collection and evaluate results, permitting timely termination or redirection of an experiment. Man can, through receipt and delivery of components via a logistics vehicle, configure a variety of experiments each of which could require a separate unmanned vehicle. Thus, man can enter into the operations loop, extending the usefulness of standard laboratory equipment. For example, the basic receiver, transmitter and data processing sections of the proposed experiments offer significant possibilities for the use of common modules and plug-in modules to accommodate a variety of experiments. Calibration necessary for quantitative measurements is simply accomplished by man, who may adjust ranges to those desired.

Man may monitor an error signal indicating that a tracking system is maintaining or losing lock. Since measurement periods are often short, man may observe the entire period – possibly regaining lost lock through manual override.

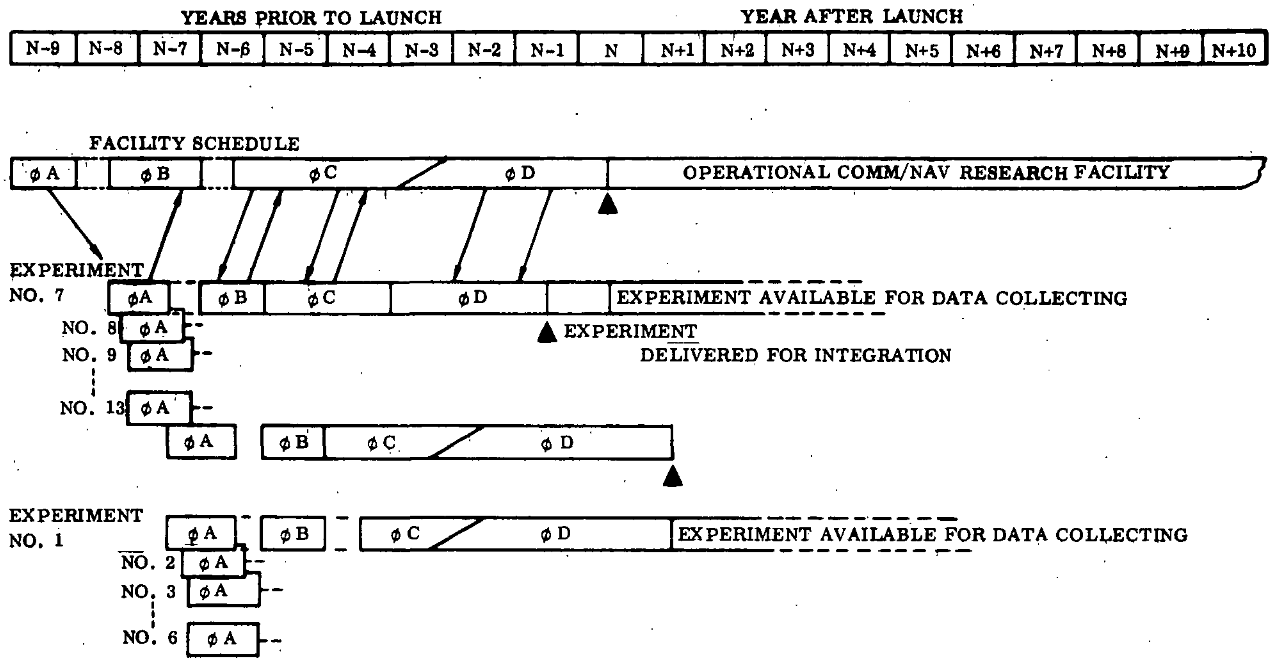
Man may accomplish limited repairs as well as plug-in changes reducing the required redundancy in equipment.

Man's ability to engage in activities outside the spacecraft (EVA) greatly simplifies the assembly of units that must go into space in a folded (furled) condition. Table 1-4 indicates various cases of possible EVA, usually in connection with erection and changing feeds of antennas. The elimination of unnecessary EVA, however, must be a consideration in performing all experiments.

1.8 SCHEDULES

Typical experiments have been described to permit determining the requirements for a Communications/Navigation Research Facility. These requirements permit scheduling early description of the facility. As design commences, more detailed planning of experiments by principal investigators will permit an interchange between the facility and experiment designers to firm-up existing or reveal additional requirements and constraints.

The schedule shown in Figure 1-21 commences in a period before launch leading to a completed Communications/Navigation Research Facility ready for launch and compatible with the experiments which have meanwhile been completed for integration and flight.



NOTE: Experiment schedules shown are "TYPICAL"; time phasing of facility definition and development is considered realistic.

Figure 1-21.

1.9 PRELAUNCH SUPPORT REQUIREMENTS AND GSE

It has been stated previously that the use of man in conducting space experiments not only allows him to conduct operations in the experimental procedure but also to exercise his judgment in deciding status and direction of experimentation. It is consistent with the use of man to simplify (not eliminate) prelaunch and ground support requirements. This is compatible with the use of equipment items that are less automated. Items peculiar to the experiments would be supported as follows:

a. Complete functional check in laboratory prior to loading in launch vehicle.

b. Using ground power, antenna loads, couplers or radiative links, check out all experiment equipment as close to launch as prelaunch procedures permit. This checkout would be accomplished by man in the space vehicle to eliminate the cost and complexity of added automation. This checkout would give the necessary assurance that equipment is operative at time of launch.

1.10 SAFETY ANALYSIS

Communications and navigation experiments present all the usual hazards associated with manned spaceflight. The potential hazards that are a consequence of a particular experiment are viewed as:

a. A direct result of man's contact with the experimental equipment.

b. An experiment that adversely affects man's life support environment in space.

Table 1-8 itemizes a number of potential hazardous areas and some of the related precautionary measures.

1.11 AVAILABLE BACKGROUND DATA

Sources used for background to aid in writing experiments are listed below in the order in which they appear in the individual experiment writeups.

a. W. K. Pratt, Laser Communications Systems, Wiley, 1969.

b. Earth Orbital Experiment Program and Requirements Study, NASA, LaRC Contract No. NAS1-9464, McDonnell-Douglas Corporation and TRW Systems (subcontractor).

c. B. R. Bean and E. J. Dutton, Radio Meteorology, National Bureau of Standards Monograph No. 92, March 1960.

d. Memorandum, S. W. Fordyce to R. W. Johnson (NASA Headquarters), A Radio Frequency Spectrum Analysis Experiment for the Manned Space Station Program, 7 May 1970.

e. Feasibility Study of Man-Made Radio Frequency Radiation Measurements from a 200-Mile Orbit, Report No. GDC-ZZK68-007, Convair Division of General Dynamics, NASA Contract NASW1437, 15 February 1968.

f. Plasma Physics and Magnetohydrodynamics in Space Exploration, NASA SP-25, Office of Scientific and Technical Information, December 1962.

g. Minutes of NASA Review Group Meeting on COM/NAV Blue Book Update, held at NASA Headquarters, 7 July 1970.

h. Minutes of Second NASA Review Group Meeting on COM/NAV Blue Book Update, held at the Convair Division of General Dynamics, 22 July 1970.

i. Communications and Navigation, Program Documentation, Planning Panel on Communications and Navigation, NASA Headquarters, 1 May 1969.

Table 1-8. Safety Analysis

Potential Hazards	Precautionary Measures
MAN'S INTERFACE WITH EXPERIMENT 1. Electrical Shock	1. Proper design must provide enclosures, interlock switches, grounding and bonding to eliminate exposed high-potential points and prevent dangerous potential differences between externally exposed surfaces. This includes any items that must be handled during EVA.
2. Radiation Burns a. Eyes vulnerable to laser (Exp. 1.4.1 & 5)	2a. Lasers should be shielded and pointed so radiation cannot reach man. Eye-protective goggles are needed if other measures cannot give high confidence of protection,
b. Skin vulnerable to RF Burns (eyes on longer term basis)	2b. RF generation systems require shielding if any radiation other than from antennas is above the acceptable limit of 10 mW per cm^2. Procedures used must not permit hazardous RF radiation during EVA. (Note: Radiation exposure criteria are currently controversial, and liable to change.)
3. Cuts from Sharp Points, Edges a. On man's body – handling equipment in C/NRF	3a. Sharp points and edges should be eliminated on exposed equipment and on modules that must be moved in setup, calibration and maintenance.
b. Protective Clothing – largely during EVA (e.g., around erectable antennas and other items that cannot have all smooth external surfaces).	3b. Stored items, such as some antennas, solar panels, and various sensors which must be unfurled or assembled outside the spacecraft almost certainly present some hazards of snagging or fouling of lines (safety lanyards, tool connections or life support). Precautions such as use of generally tough materials, possibly line storage on reels, and particular care in movements should be observed.
EXPERIMENT INTERFERENCE WITH SPACECRAFT ENVIRONMENT 1. Damage to Vehicle a. Explosion	1a. Explosion-proofing is largely related to the composition of the breathing atmosphere and the presence of highly flammable materials and flames or arcs. Experiment materials are not likely to be highly flammable. Precautions in addition to use of fireproof or retardant materials include arc suppression thru circuit design, enclosed (tight vacuum or inert gas) switches, and solid-state switching. High-reliability parts are needed any place a failure may cause arcing in presence of combustibles.
b. Fire	1b. Fire precautions, in addition to explosion protection, are temperature related and include heat sinking and overheating thermostat switches, etc.
2. Pollution of Life Supporting Atmosphere a. Combustion	2a. Insofar as possible equipment ventilation systems should be isolated from space vehicle breathing atmosphere, with traps for pollutants.
b. Excessive temperature	2b. Excessive temperature related to equipment operating is controlled by heat sink and removal unless useful for heating the living environment.